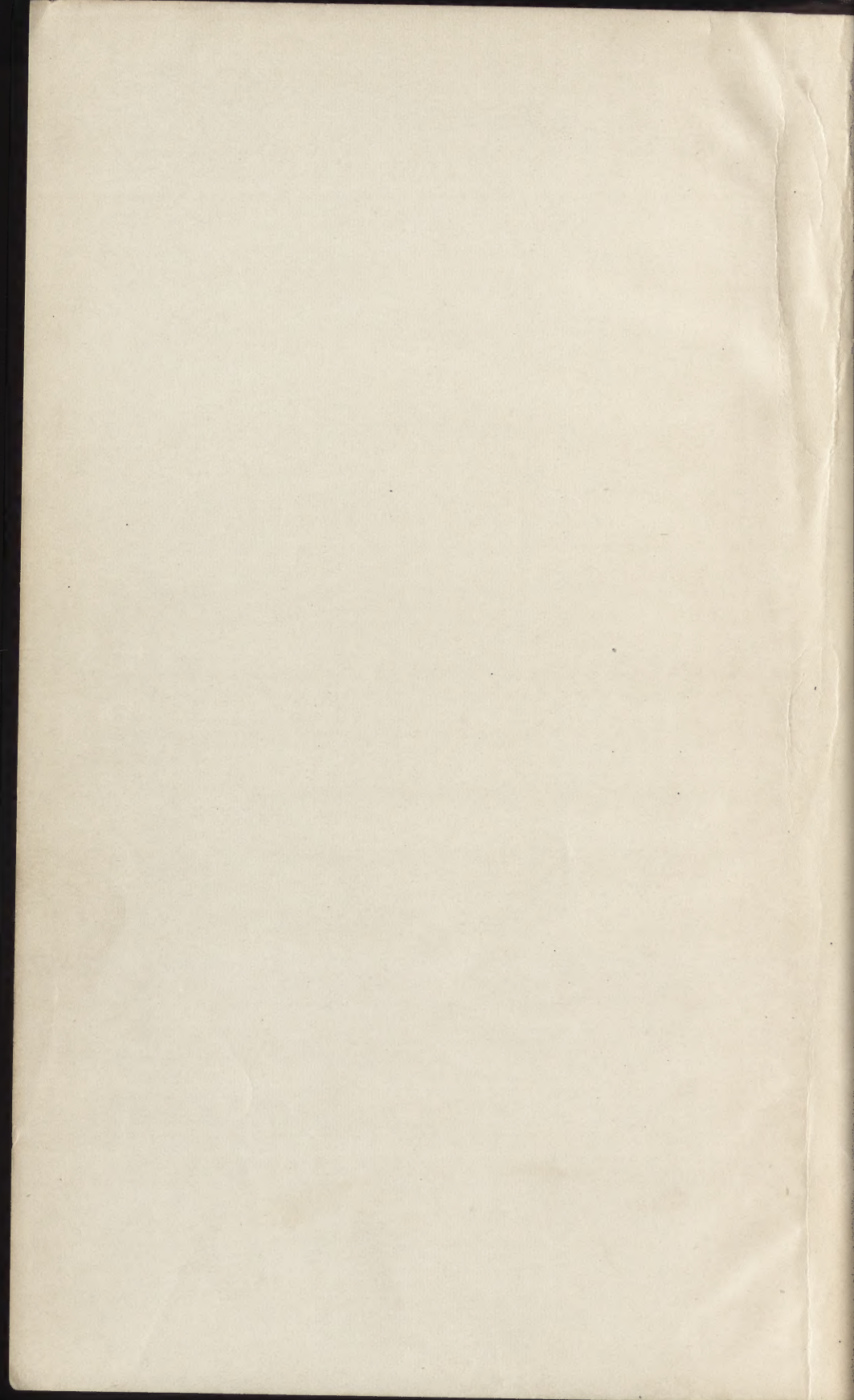


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THE TEXTILE FIBRES.

THEIR PHYSICAL, MICROSCOPICAL,

AND

CHEMICAL PROPERTIES.

FRANKLIN INSTITUTE

BY
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PREFACE.

THE present book, it is hoped, will be of assistance to both the practical operator in textiles and the student on textile subjects. It has been the outgrowth of a number of years of experience in the teaching of textile chemistry, as well as practical observation in the many mill problems which have come under the notice of the author.

The textile fibres form the raw materials for many of our greatest industries, and hence it is of importance that the facts concerning them should be systematized into some form of scientific knowledge. The author has attempted, however, not to allow the purely scientific phase of the subject to overbalance the practical bearing of such knowledge on the every-day problems of industry.

Heretofore, the literature on the textile fibres has been chiefly confined to a chapter or two in general treatises on dyeing or other textile subjects, or to specialized books such as Höhnel's work on the microscopy of the fibres. It has been the author's endeavor, in the present volume, to bring together, as far as possible, all of the material available for the study of the textile fibres. Such material is as yet incomplete, and rather poorly organized at its best; but it is hoped that this volume may prove a stimulus along the several lines of research which are available in this field. Unfortunately, the subject of the textile fibres has been lamentably neglected by chemists, although there is abundant indication that a fertile field of research is open to chemists in this direction, and such work would have not only a scientific value, but might also lead to great industrial worth. There is, as yet, relatively little known concerning the chemical

constituents of the fibres, and the manner in which varying chemical conditions affect the composition and properties of these constituents. The action of various chemical agents on the fibre as an individual has been but very imperfectly studied. More work has been done in the microscopical field concerning the properties of the fibres; but even here, the knowledge is very incomplete and disjointed, and especial attention is drawn to the fact there is yet a large amount of work to be done in the microchemistry of the subject.

The author has endeavored to emphasize throughout this volume the importance of the study of the fibre as an individual, for in many cases it is misleading to assume that the behavior of the individual fibre is identical with that of a large mass of fibres in the form of yarn or cloth. In the latter case, the difference in physical condition and the action of mechanical forces has an important influence. By going back to the study of the individual fibre as a basis, many explanations can be given which could not be discovered otherwise.

It is hoped that this book may afford instruction both to the manufacturer and to the student; assisting the former in solving some of the many practical problems constantly occurring in the manufacture of textiles, and urging the latter on to an increased effort in the scientific development of the subject.

J. MERRITT MATTHEWS.

PHILADELPHIA TEXTILE SCHOOL,
August, 1904.

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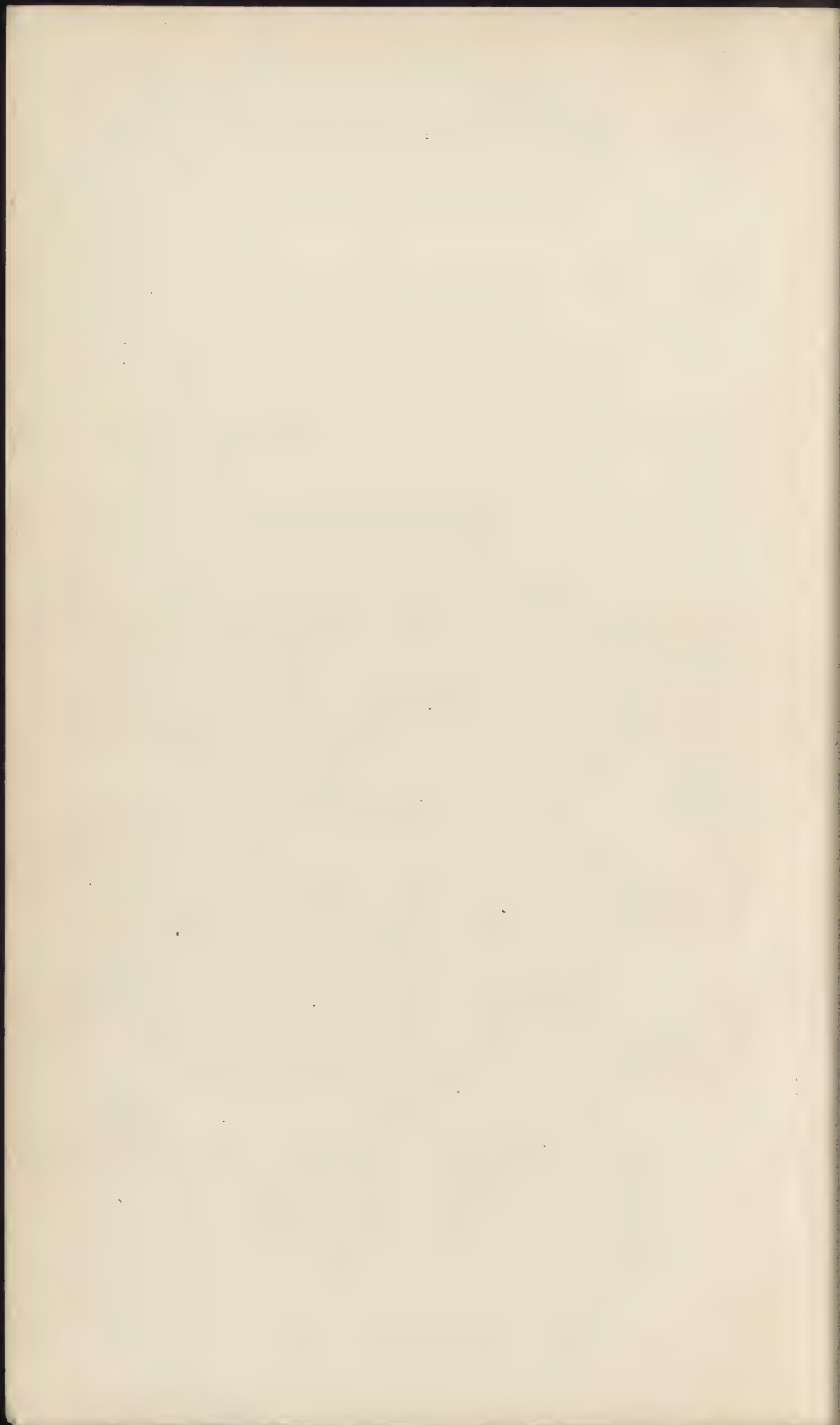
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THE TEXTILE FIBRES.

CHAPTER I.

CLASSIFICATION OF THE TEXTILE FIBRES.

1. Fibres Chiefly Used for Textiles.—In order to be serviceable in a textile fabric, a fibre must possess sufficient length to be woven and a physical structure which will permit of several fibres being spun together, thereby yielding a continuous thread of considerable tensile strength and pliability. Although there are several fibres, such as spun glass, asbestos, various grasses, etc., which are used for the manufacture of textiles in peculiar and rare instances, yet the fibres which are employed to the greatest extent and which exhibit the most satisfactory qualities are wool, silk, cotton, and linen. All of these possess an organized structure, and are the products of a natural growth in life processes.

According to Georgevics, all textile fibres may be divided into four distinct classes; and though the same general arrangement is here preserved, the order has been somewhat changed so as to bring the most prominent ones first: (1) *Animal fibres*; (2) *Vegetable fibres*; (3) *Mineral fibres*; (4) *Artificial fibres*.

2. Animal and Vegetable Fibres.—According to their origin, we may divide the principal fibres into two general classes, those derived from animal and those derived from vegetable life. The former includes wool and silk, and the latter cotton and linen. Animal fibres are essentially nitrogenous substances (protein

matter), and in some cases contain sulphur. They may be solid filaments formed from a liquid secretion of certain caterpillars, spiders, or molluscs. Alkalies readily attack the animal fibres, causing them to be dissolved, but they withstand the action of mineral acids to a considerable degree. Contrary to the vegetable fibres, they are readily injured if exposed to elevated temperatures. Vegetable fibres consist of plant-cells, usually rather simple in structure and forming an integral part of the plant itself. They are capable of withstanding rather high temperatures, and are not weakened or disintegrated by the action of dilute alkalies. They consist essentially of cellulose, which may be in a very pure form, or be mixed with its various alteration products. In some cases the fibre consists of some cellulose derivative obtained by chemical means, such, for instance, as mercerized cotton. Concentrated alkalies produce alteration products with the vegetable fibres. Free sulphuric or hydrochloric acid, even if only moderately strong, will quickly attack the fibre, disintegrating its organic structure and forming hydrolyzed products. Nitric acid, on the other hand, forms nitrocelluloses and various oxidation derivatives.

3. Mineral and Artificial Fibres.—These two classes of fibres are of rare occurrence in the textile industry when compared with the extensive use of the preceding fibres. They find a limited use, however, for certain purposes, and deserve to be considered in a systematic study of the subject. The principal, and strictly speaking the only, mineral fibre is asbestos, which occurs in nature as the mineral of that name. It is a fibrous silicate of magnesium and calcium, though often containing iron and aluminium in its composition, especially in the dark-colored varieties. This mineral, though in the form of a hard rock, can be easily separated into slender white fibres, sometimes inclining towards a greenish color. The fibres of some varieties (Canadian) are curly, and afford the best material for spinning. In general, however, the fibres of asbestos are straight and glassy in structure, and are difficult to spin into a coherent thread. In order to enhance its spinning qualities it is mixed with a little cotton, the latter fibre being subsequently destroyed by heating the woven

fabric to incandescence. At the present time quite a variety of fabrics are manufactured from asbestos fibre, and the high quality of many articles appearing on the market shows that the art of manipulating this substance has reached a high degree of perfection. On account of its incombustible nature, and as it is a very poor conductor of heat, it is made into fabrics where these qualities are especially desired. Thus it is frequently manufactured into gloves and aprons, packing for steam-cylinders, theatrical curtains and scenery, lamp-wicks, etc. The latter use of asbestos was known to the ancients, who employed it for the wicks of the perpetual lamps in their temples. It is from this fact, indeed, that it received its name, the word "asbestos" meaning "unconsumed." It was also employed for napkins on account of its being readily cleansed, it only being necessary to heat the fabric in a flame to make it clean again. Asbestos, in general, is not dyed, and does not undergo any chemical processes or modes of treatment. When it is desirable to dye it the various substantive dyes may be used with good effect, or the color may be applied by mordanting with albumen.

The artificial fibres may be divided into two groups: (a) those of mineral origin and (b) those of animal or vegetable origin. In the first division may be classed such fibres as spun glass, metallic threads, and slag wool; in the second division may be put the various artificial silks, such as lustra-cellulose and gelatin silk.

Fibres of spun glass are prepared by drawing out molten glass in the form of very fine threads; colored glasses may be used to give rise to variously colored threads. Owing to its brittle nature and lack of elasticity, spun glass receives a very limited application, it being made into various ornamental objects, and sometimes into cravats. A variety of spun glass known as glass wool is used to some extent in the chemical laboratory as a filtering medium for liquids which would destroy ordinary filter-paper. Glass wool is curly, this property being given to it by drawing out the glass thread from two pieces of glass of different degrees of hardness; and by unequal contraction on cooling, this double thread curls up.

Various metals are at times drawn out into threads for use in decorative fabrics. Gold, silver, copper, and various alloys are used for this purpose. At the present time metallic threads are largely imitated by coating linen yarns with a thin film of gold or silver.

Slag wool is prepared by blowing steam through molten slag; it can scarcely be called a textile fibre, but it is used in some degree as a packing material.

Artificial silks are made either from cellulose derivatives or gelatin by forcing solutions of these through fine capillary tubes and coagulating the resulting threads and subsequently subjecting them to various processes of chemical treatment. As these belong more strictly to the class of true textile fibres, they will be given a more extensive consideration, in a further section, as being derivatives of cellulose.

CHAPTER II.

WOOL AND HAIR FIBRES.

1. THE woolly, hair-like covering of the sheep forms the most important and the most typical of the textile fibres which are obtained from the skin tissues of different beasts. The hairy coverings of a large number of animals are employed to a greater or lesser extent as raw materials for the manufacture of different textile products, but those of the various species of sheep make up the great bulk of the fibres which possess any considerable technical importance. Hairs, derived from whatever species of animals, have very much in common as to their general physical and chemical properties; they are also similar with respect to their physiological origin and growth. The hairs, however, of different animals, vary much in the detail of their special characteristics, and also with regard to their adaptability for use in the textile industry; and the wool of the sheep appears to exhibit in the highest degree those specific properties which make the most suitable textile fibre. These properties may be enumerated as being: (*a*) Sufficient length, strength, and elasticity, together with certain surface cohesion, to enable several fibres to be twisted or spun together so as to form a coherent and continuous thread or yarn; (*b*) the power of absorbing coloring-matters from solution and becoming dyed thereby, and also the property of becoming decolorized or bleached when treated with suitable chemical agents; (*c*) in addition to these qualities, which they have in common with almost any textile fibre, wool fibres also possess the quality of becoming felted or matted together, due to the peculiar physical character of their surfaces. This property

is a most valuable one, as it adapts wool to a large number of uses to which other fibres are unsuitable.

Silk is also a member of the general group of animal fibres, and though it possesses certain general chemical characteristics in common with wool and hair, yet it has an entirely different physiological origin, being a filament of animal tissue excreted by a certain species of caterpillar, and hence is totally different from wool in its physical properties. Wool may be specifically designated as a variety of hair growing on certain species of mammalia, such as sheep, goats, etc. The unmodified term "wool" has special reference to the product obtained from the different varieties of sheep. Cashmere, mohair, and alpaca are the products obtained from the thibet, angora, and llama goats, respectively. Fur is also a modified form of hair, but differs from wool in many of its physical properties, and is not adapted for use in the manufacture of spun textiles. It is, however, largely employed for the making of hat felts.

The wool-bearing animals all belong to the order Ruminantia, which includes those animals that chew their cud or ruminate. The principal members of this order are sheep, goats, and camels. The sheep belongs to the class *Ovidæ*, and occurs in a number of species which vary considerably in form and geographical distribution, as well as in the character of the wool it produces. Broadly considered, naturalists divide the sheep into three different classes:

(a) *Ovis aries*, commonly known as the domestic sheep, and cultivated more or less in every country in the world.

(b) *Ovis musmon*, occurring native in the European and African countries bordering on the Mediterranean Sea.

(c) *Ovis ammon*, which includes the wild or mountain sheep (*argali*) to be found in Asia and America. The big-horn sheep of the Rocky Mountains belongs to this class.*

* A more detailed classification than the above is given by Archer, who divides the sheep into thirty-two varieties:

1. Spanish, or merino sheep (*Ovis hispaniam*).
2. Common sheep (*Ovis rusticus*).
3. Cretan sheep (*Ovis strepsiceros*).

The domestic sheep is the most important of these classes. It can hardly be said to be indigenous to any one country, for it appears to have been cultivated by the earliest peoples in history, and it has spread over the entire face of the globe with the gradual extension of civilization itself. Different conditions of climate and soil, of pasturage and cultivation, appear to exert a considerable influence on the variety of the sheep and on the character of the wool it eventually produces. Variations are also produced

-
4. Crimean sheep (*Ovis longicandatus*).
 5. Hooniah, or black-faced sheep of Thibet.
 6. Cago, or tame sheep of Cabul (*Ovis cagia*).
 7. Nepal sheep (*Ovis selingia*).
 8. Curumbar, or Mysore sheep.
 9. Garar, or Indian sheep.
 10. Dukhun, or Deccan sheep.
 11. Morvant de la chine, or Chinese sheep.
 12. Shaymbliar, or Mysore sheep.
 13. Broad-tailed sheep (*Ovis laticandatus*).
 14. Many-horned sheep (*Ovis polyceratus*).
 15. Pucha, or Hindoostan dumba sheep.
 16. Tartary sheep.
 17. Javanese sheep.
 18. Barwall sheep (*Ovis Barnal*).
 19. Short-tailed sheep of northern Russia.
 20. Smooth-haired sheep (*Ovis Ethiopia*).
 21. African sheep (*Ovis Grienensis*).
 22. Guinea sheep (*Ovis ammon Guinensis*).
 23. Zeylan sheep.
 24. Fezzan sheep.
 25. Congo sheep (*Ovis aries congensis*).
 26. Angola sheep (*Ovis aries angolensis*).
 27. Yenu, or goitred sheep (*Ovis aries steatiniora*).
 28. Madagascar sheep.
 29. Bearded sheep of west Africa.
 30. Morocco sheep (*Ovis aries munædæ*).
 31. West Indian sheep of Jamaica.
 32. Brazilian sheep.

These represent the naturally occurring classes of sheep in the different countries; of course, a large number have been emigrated and domesticated in other countries than those in which they had their origin, which has given rise to several sub-varieties. Then, too, new varieties have been formed by cross-breeding and intermixing, which has brought about a considerable variation in the type. The latter is also influenced very largely by climatic conditions, geographical environment, and character of pasturage.

by cross-breeding and intermixing, and the nature of the fibre has been much altered and improved by careful selection in breeding and genealogical development.

Sheep in their natural condition produce two kinds of hair: the one giving a long, stiff fibre, which we will call "beard-hair"; and the other a shorter, softer, and more curly fibre, which we will designate as "wool-hair," or true wool. By domestication and proper cultivation the sheep can be made to produce the latter kind of hair almost exclusively, with but little or none of the hairy fibre. Herein the sheep differs essentially from the goat, as the latter will always produce both kinds of fibre, though the fineness and quality of its hair may be much improved by proper cultivation. In addition to the above-mentioned varieties of hair, most sheep grow more or less of short, stiff hairs, or undergrowth; these have no value as textile fibres. It must be mentioned, however, that the exact character of the wool on the individual sheep varies considerably with its position in the fleece; on the extremities of the animal the wool becomes more hairy in nature, and near the feet the short undergrowth of stiff hair is alone to be found. The texture, length, and softness of the fibre also differ considerably in different portions of the fleece. Hence it becomes necessary, in order to obtain a homogeneous mixture of fibres with properties as constant as possible, to sort out the fibres of the fleece into different portions, which are put together into different grades of wool stock. This operation is termed wool-sorting and grading, and is an important step in the manufacture of wool. Different varieties of wool may require different systems and degrees of sorting, but in general the fleece is roughly divided into nine sections, given as follows:

(1) The shoulders and sides of the fleece give the finest and most even staples of fibre.

(2) The lower part of the back yields a fibre of fairly good staple.

(3) The loin and back give a shorter staple, and the fibre is not as strong.

(4) The upper part of the legs give a staple of moderate length. The fibre on this part is frequently in the form of loose,

open locks and acquires a large amount of burrs by brushing against the spinose fruit of the plant; the presence of these burrs considerably lessens the commercial value of the wool. South American wool is especially liable to be heavily charged with burrs.

(5) The upper part of the neck gives a rather irregular staple which is also very frequently filled with burrs.

(6) The centre of the back gives a fine delicate staple similar to that from the loins.

(7) The belly, together with the wool from the fore and hind legs yields a poor staple and a weak fibre.

(8) The tail gives a short, coarse, and lustrous fibre, frequently containing a considerable amount of kemps.

(9) The head, chest, and shins give a short, stiff, and straight fibre, opaque and dead white in color.

The merino sheep, which yields what is considered to be the finest quality of wool, appears to have originated in Spain, and at one time was extensively cultivated by the Moors. The exportation of merino sheep from Spain was long guarded against with great care, no one being allowed to take a live merino sheep out of the kingdom of Spain under penalty of death. Later, however, this sheep was brought into various countries, being crossed with the different local breeds with very beneficial results. A German derivative of the Spanish merino known as the Saxony Electoral merino, gives perhaps the highest grade of fibre known in Europe. Australian sheep are mostly derived from merino and other high-class stock and yield a wool of the very highest quality. The merino has been cultivated and crossed with other breeds throughout the various parts of the United States, and the latter country is gradually becoming a large producer of middle grade wool.

2. Physiology and Structure of Wool.—Wool, in common with all kinds of hair, is a growth originating in the skin or cuticle of the vertebrate animals, and is similar in its origin and general composition to the various other skin tissues to be found in animals, such as horn, nails, feathers, etc. Wool is an organized structure growing from a root situated in the dermis or middle

layer of the skin; its ultimate physical elements being several series of animal cells of different forms and properties. Herein it differs essentially from silk, which is not composed of cells, but is a continuous and homogeneous tissue. The root of the wool fibre is termed the hair follicle (Fig. 1); it is a gland which secretes

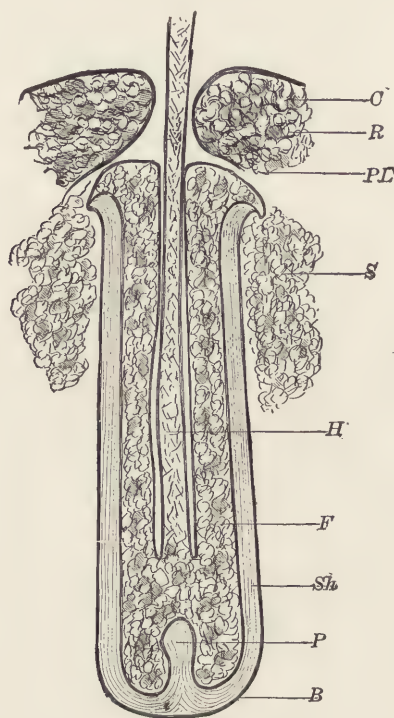


FIG. 1.—Section of Hair Follicle.

C, cuticle of skin; *R*, rete mucosum; *PL*, papillary layer; *S*, sebaceous glands; *P*, papilla; *B*, bulb of hair; *H*, hair; *F*, fibrous tissue; *SH*, transparent sheath.

a lymph-like liquid, from which the hair is gradually developed by the process of growth. The hair follicle also secretes an oil, which is supplied to the fibre during its growth, and serves the purpose of lubricating its several parts, giving it pliability and elasticity. In conjunction with the hair follicle there also occur in the skin numerous sebaceous glands which secrete a fatty or waxy substance, commonly known as wool-fat. This substance

gradually exudes from the glands and coats the surface of the wool in rather considerable amount (Fig. 2). It affords a protective coating to the fibre which serves to preserve the latter from mechanical injury during its growth, and also prevents the several fibres from becoming matted and felted together. In the preparation of wool for manufacture, this fatty covering has to be removed, the operation constituting the ordinary process of wool scouring. The oil, on the other hand, which is contained in the substance of the fibre itself, and is a true constituent of its sub-

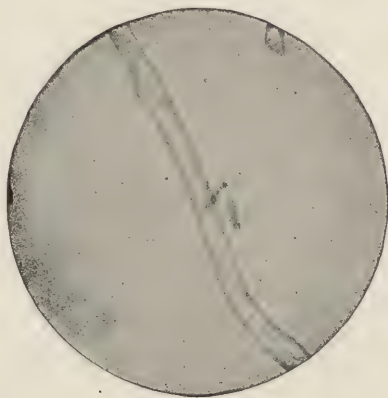


FIG. 2.—Wool Fibre in the Natural Grease ($\times 350$).

The markings of the scales are scarcely apparent owing to the interstices being filled with greasy matter.

stance, should not be removed, as its removal causes the fibre to lose much of its elasticity and resiliency. This oil amounts to about one per cent. of the total weight of the fibre, whereas the external fatty matter amounts on an average to about 30 per cent.

Morphologically considered, the wool fibre consists of three distinct portions: (*a*) A cellular marrow, or medulla, which frequently contains more or less pigment matter to which the wool owes its color; (*b*) A layer of cellular fibrous substance or cortical tissue which gives the fibre its chief strength and elasticity; (*c*) An outer layer or epidermis of horn tissue, consisting of flattened cells, or scales, the ends of which generally overlap each other, and project outwards, causing the edge of the fibre to present a serrated appearance (Fig. 3). This scaly covering

gives the fibre its quality of rigidity and resistance to crushing strain; it also causes the fibres to felt together on rubbing against one another by the interlocking of the projecting edges of the scales (Fig. 4).

Any one of these three physical constituents may at times be lacking in a fibre. When the epidermal scales are absent, they have simply been rubbed off by friction; this condition is fre-

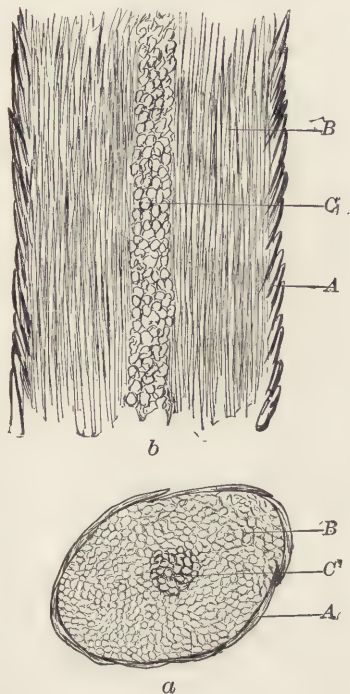


FIG. 3.

FIG. 3.—Sections of Wool or Hair Fibre.

a, cross-section of fibre; *b*, longitudinal section of fibre; *A*, epidermal layer of scales; *B*, cortical layer of fibrous cells; *C*, medullary layer of round cells.

FIG. 4.—Diagram Showing Felting Action of Wool.

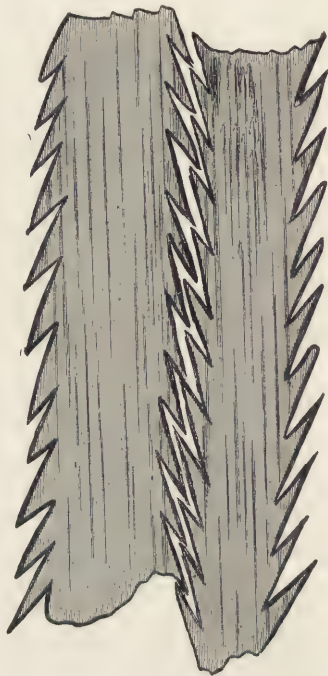


FIG. 4.

quently to be found at the ends of long beard-hairs. The cortical layer of fibrous tissue is frequently but slightly developed, especially in cases where the medulla is large: in some instances, indeed (as in the hair of the doe), the cortical layer appears to be totally absent in the broadest parts of the fibre. The medulla is very

frequently absent, or, at least, shows no difference in structure from the cells of the surrounding cortical layer; this occurs more especially in the wool-hairs, but is also to be found in beard-hairs. On the other hand, the medulla is more largely developed than the cortical layer, and becomes the principal part of the fibre, as in the beard-hairs of the doe.

The microscopic appearance of wool is sufficiently characteristic to distinguish it from all other fibres. Under even moderately low power of magnification the scales on the surface of the fibre can be readily discerned, while neither silk nor the vegetable fibres present this appearance (Fig. 5). The scales



FIG. 5.—Various Fibres. (Bowman.)

A, Chinese wool; B, merino wool; C, cotton; D, silk; E, mohair.

are more or less translucent in appearance, and permit of the under cortical layer being seen through them. The exact nature and structure and arrangement of the scales differ considerably with different varieties of wool. In fine merino wools, for instance, the individual scales are in the form of cylindrical cusps, one somewhat overlapping the other; that is to say, a single scale completely surrounds the entire fibre (Fig. 6). In some varieties of wool, on the other hand, two or more scales occur in the circumference of the fibre. In some cases the edges of the scales are smooth and straight (Fig. 7), and this appears to be especially characteristic of fine qualities of wool; the coarser species, on the other hand, possess scales having serrated wavy

edges. Usually such scales are much broader than they are long and are very thin (Fig. 8). The length of the free or projecting

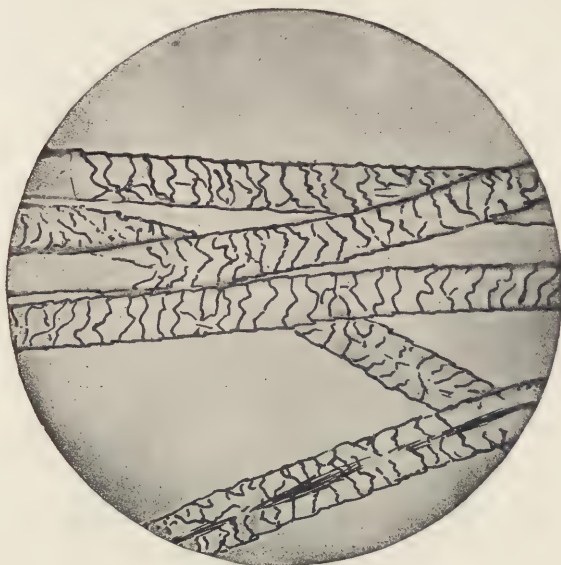


FIG. 6.—Typical Wool Fibres ($\times 500$).

From a camera lucida micrograph, showing the irregular surface scales and the faint striations of the underlying fibrous layer of cortical tissue; the presence of the medullary cells is also plainly visible in one fibre.

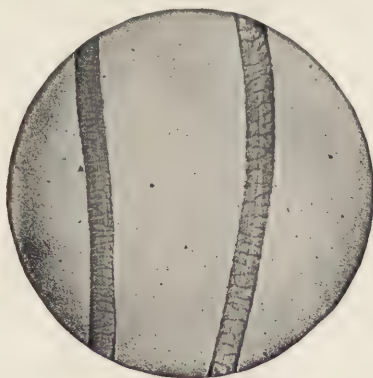


FIG. 7.—Wool Fibre ($\times 350$).

With smooth, straight scales of a non-felting type.

edge of the scale is also a very variable factor; in some wools the scale is free from the body of the fibre for about one-third of the

length of the former, and in consequence the scale protrudes to a considerable extent; such wool would be eminently suitable for the preparation of material which requires to be much felted (Fig. 9). In other wools, the free edge of the scale amounts to almost nothing, and the separate members fit down on one another closely, and are arranged like a series of plates. Wools of this class are more hair-like in texture, being stiffer and straighter,

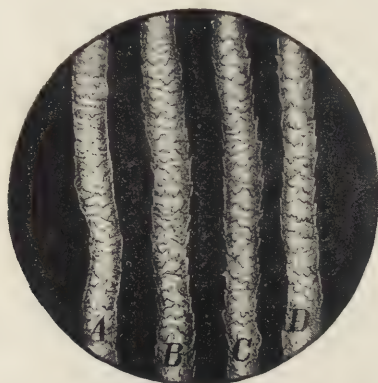


FIG. 8.

FIG. 8.—American Merino Wool. (Bowman.)

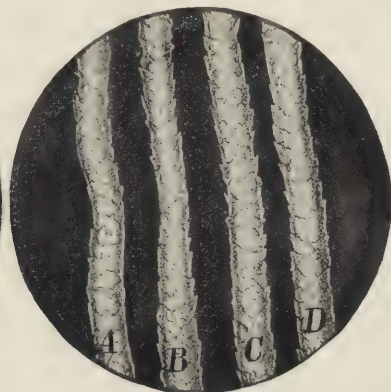


FIG. 9.

FIG. 9.—Australian Botany Wool. (Bowman.)

In fibres *A* and *B* irregularities in diameter may be noticed; but in fibres *C* and *D* the diameter is very uniform.

and not capable of being readily felted (Fig. 10). The wool-hairs (the long, stiff fibres which have already been mentioned as occurring to a greater or lesser degree in nearly all wools, also known as beard-hairs) usually possess this structure. The felting quality of wool is much increased by treatment with acid or alkaline solutions, or even boiling water, the effect being to open up the scales to a greater extent, so that they present a much larger free margin and consequently interlock more readily and firmly. Woolen yarns, and woven materials made from such yarns, felt much more easily than worsted yarns, due to the fact that the fibres of the former lie in every direction and the interlocking of the scales takes place more easily.

In some varieties of wool fibre the scales have no free edge at all, but the sides fit tightly together with apparently no overlap-

ping; in such fibres the surfaces of the scales are also more or less concave (Fig. 11). This structure only occurs with thick, coarse varieties of wool. Frequently at the ends of the wool fibre, where the natural point is still preserved (as in the case of

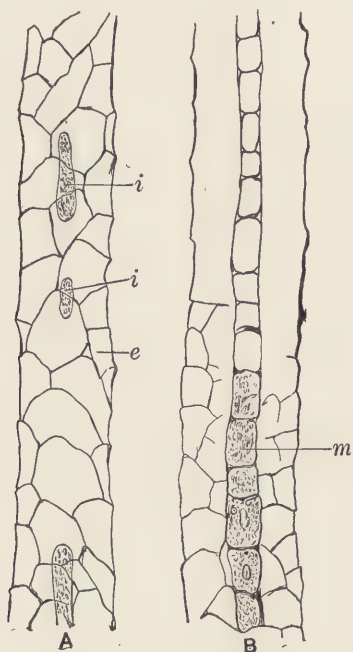


FIG. 10.—Wool Fibre with Plate-like Scales. (Höhncl.)
A, portion of fibre with isolated medullary cells at *i*, and smooth scales *e* fitting together like plates; *B*, portion of fibre showing medullary cylinder at *m*.

lamb's wool from fleeces which have not been previously sheared), the scales are more or less rubbed off and the under cortical layer becomes exposed (Fig. 12); this appearance is quite characteristic of certain wools. In diseased fibres the epidermal scales may also be lacking in places, causing such fibres to be very weak at these points (Fig. 13).

In most varieties of wools the scales of the epidermis may be readily observed even under rather low powers of magnification, while under high powers the individual scales may be seen overlapping one another like shingles on a roof, and showing pointed,

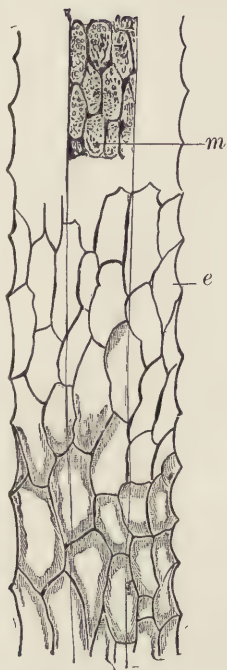


FIG. 11.

FIG. 11.—Wool Fibre with Concave Scales. (Höhnel.)

m, medullary cylinder consisting of several rows of cells; *e*, concave scales arranged in a plate-like manner.



FIG. 12.

FIG. 12.—Showing Wool Fibre with Scales Rubbed Off. (Höhnel.)

e, residue of epidermis; notice the coarse striations of the cortical layer underneath the epidermis.



FIG. 13.—Kempy Wool Fibres. (Bowman.)

A, fibre with incomplete development of scales; *B*, fibre with scales undeveloped in certain parts only; *C* and *D*, diseased fibres.

thickened protuberances at the edges. When the fibre becomes more hair-like in nature, such as mohair, alpaca, camel's hair, etc., it is more difficult to observe the individual scales, as these fuse together to a greater or lesser degree, until the true hair fibre is reached, which exhibits scarcely any markings of scales at all under ordinary conditions. By treatment with ammoniacal copper oxide, however, the interscalar matter is dissolved away, and even with true hair the scaly nature of the surface may be observed. Bowman gives the approximate comparative number of scales in different varieties of wool as follows:

Wool.	Scales, per inch.	Diam. of Fibre (ins.).
East Indian.	1000	0.00143
Chinese.	1200	0.00133
Lincoln.	1400	0.00091
Leicester.	1450	0.00077
Southdown.	1500	0.00080
Merino.	2000	0.00055
Saxony.	2200	0.00050

The epidermal layer of scales imparts to the wool fibre its characteristic quality of lustre. Since the lustre of any surface is due to the unbroken reflection of light from that surface, it may be readily understood that the smoother the surface of the fibre, the more lustrous it will appear. When the epidermal scales are irregular and uneven, and have projecting points and roughened edges, the surface of the fibre will naturally not be very smooth and uniform, and consequently will reflect light in only a broken and scattered manner. Such fibres will not have a high degree of lustre. On the other hand, when the scales are regular and uniform in their arrangement, and their edges are more or less segmented together to form a continuous surface, the fibre will be smooth and lustrous. As a rule, the coarser and straighter fibres are the more lustrous, as they approximate more closely to the structure of hair, which has a smooth surface. The lustre of the fibre being dependent on the polished surface of the scales is influenced largely by any condition which may affect the latter. Treatment with chemical agents, for instance, which will corrode the horny tissue of the scales, will seriously affect the lustre, as is evidenced by allowing alkaline solutions to

act on lustrous wool fibres. High temperatures (and especially dry heat) corrodes the epidermal scales and shrivels them up, causing the fibre to lose its lustre. In the various mechanical processes through which the wool must pass in the course of its manufacture, the scales of the fibre suffer more or less injury, being torn apart, roughened, and loosened from the surface. In order to minimize the extent of this injury the wool is generally oiled, so that the surface of the fibres may be properly lubricated.

The rigidity and pliability of the wool fibre is also largely conditioned by the nature of its epidermal scales. If these fit over one another loosely with considerable length of free edge, the fibre will be very pliable and plastic, soft and yielding, also easily felted. Whereas, if the scales fit closely against one another and have little or no freedom of movement, the fibres will be stiff and resistant, and not easily twisted together nor felted.

The cortical layer, or true fibrous portion of the fibre, forms the major constituent of wool. It consists principally of more or less elongated cells, and often presents a distinctly striated appearance, the striations being visible through the translucent layer of scales. The individual cells measure from 0.0025 in. to 0.0014 in. in length, and from 0.00066 in. to 0.00050 in. in diameter, hence are elliptical in form. The cells may be disintegrated from one another by a careful treatment with caustic alkali. To this cortical tissue the fibre chiefly owes its tensile strength and elasticity. When the fibre is fine in staple, the cortical cells exhibit more or less unevenness in their growth and arrangement, with the result that the fibre is contracted on one side or the other, giving rise to the wavy or curled appearance of such wools. It is best, perhaps, to speak of the wool being "wavy" rather than "curled," as the latter implies usually a spiral development which involves a twisting of the fibre, and in wool, as a rule, this does not occur. Coarse wools seldom exhibit this wavy structure, or only to a slight degree, the waves being long and irregular; some fine stapled wools, on the other hand, possess short and very regular waves. This property of the fibre adds much to its spinning qualities, and also to the resiliency of the yarn or fabric into which it is manufactured. Wool-hairs exhibit much less develop-

ment of waves than the true wool fibres, and the more closely the animal fibres approximate to the structure of ordinary hair, the less pronounced are the waves. Sheep's wool is more wavy than that derived from allied species, such as the various goats, camel, etc. Mohair, for instance, exhibits no wavy structure at all. The exact cause which determines the wavy quality of wool is but ill-defined; there appears, however, to be some connection between the degree of curl, the diameter of the fibre, and the number of scales per inch. The following table, given by Bowman, shows the relation between the number of waves and the diameter of the fibre:

Wool,	Waves per inch.	Diameter of Fibre (ins.).
English merino.....	24-30	0.00064
Southdown.	13-18	0.00078
"	11-16	0.00100
Irish.	7-11	0.00120
Lincoln.	3- 5	0.00154
Northumberland.	2- 4	0.00172

The waviness of the wool fibre may be temporarily removed by wetting with hot water and drying while in the stretched condition.

In tensile strength and elasticity, the wool fibre varies within large limits, depending on the breed and quality of the sheep, and also the diameter of the fibre and the part of the fleece from which it was derived. The strength of wool, and of animal hairs in general, is due to the peculiar structure of the fibre. In the first place, the external sheath of horny tissue of flattened cells which take the form of scales, offers considerable resistance to crushing strains, and are also locked rather firmly together in the direction of the length of the fibre; this has a tendency to resist any diminution in the diameter of the fibre which would be felt when the latter is stretched. Then, too, the internal cortical cells of the fibre are so arranged as to present a very firm structure, being firmly interlaced together, consequently, they offer considerable resistance to rupture. It has been noticed by a microscopical examination of a broken fibre that the cells themselves are never ruptured, but only pulled apart from one another; this is evidence that the cell-wall is of a strong texture. The latter is probably formed of a continuous tissue which is less

than 0.0002 inch in thickness, as under the highest powers of the microscope it exhibits no evidence of structural elements. Bowman gives the following table which records the average results of a number of experiments on the strength and elasticity of the wool fibre:

Wool.	Tensile Strength, grams.	Elasticity, per cent.	Diameter, ins.
Human hair.	106	36.6	0.00332
Lincoln Wool.	33	28.4	0.00181
Leicester.	31	27.3	0.00164
Northumberland.	28	27.0	0.00149
Southdown wool.	5.9	26.8	0.00099
Australian merino.	3.2	33.5	0.00052
Saxony merino.	2.5	27.5	0.00034
Mohair.	38	29.9	0.00170
Alpaca.	9.7	24.2	0.00053

It is interesting to compare these figures of tensile strength for equal cross-sections of fibre. As the cross-section varies with the square of the diameter, by taking the ratio of the latter numbers and multiplying by the tensile strength, a figure is obtained which represents the tensile strength for equal diameters of fibres. In this manner the following table has been calculated, taking human hair as the standard for comparison, as it has the largest diameter:

Human hair.	100
Lincoln wool.	96.4
Leicester.	119.9
Northumberland.	130.9
Southdown wool.	62.3
Australian merino.	122.8
Saxony merino.	224.6
Mohair.	136.2
Alpaca.	358.5
Cotton (Egyptian). . .	201.8

It will be noticed from this table that Saxony merino wool is by far the strongest of the different grades of wool. It is also interesting to note that cotton is considerably stronger than the majority of wools.

The *medulla*, or marrow, of the wool fibre consists of round or slightly flattened cells, usually somewhat larger in section than

those comprising the cortical layer. The size of the medulla varies considerably in different varieties and grades of wool, and even shows large variations in fibres from the same fleece. At times it may occupy as much as one-quarter to one-third of the entire diameter of the fibre; and again, it may be reduced to almost a line, or even disappear completely. Wool-hairs exhibit the presence of a distinct medulla more frequently than the true wool fibres. The latter mostly show scarcely any inner structure at all, though at times there may be noticed isolated medullary markings, but usually the fibre is so transparent that it presents no markings at all. In camel's hair, however, the medullary portion shows up very distinctly, in some fibres appearing as a continuous dark band occurring about three-fourths of the width of the fibre, while in other fibres it shows a well-defined granular structure. In hairs of some other animals the medullary part exhibits a structure which is distinctly characteristic of the fibre; in the hair of the cat, for instance, the medullary cells appear in a reticulated form, and in the hair of the rabbit they occur as a series of laminae very regularly superposed on each other. The medullary cells frequently contain pigment matter, either continuously or in isolated cells; and this may occur even in fibres usually classified as white wool. Sometimes the pigment permeates not only the medulla, but also the cells of the cortical layer, in which case the fibre as a whole appears colored. To this class belong the variously colored wools, ranging from a light brown to almost a black. The hair of camels, goats, and other animals is also more or less colored, and to a much more general extent than sheep's wool. The medulla may consist of a single series of cells, or of several series arranged side by side; sometimes these cells occur in a discontinuous and rather irregular manner, the intervening spaces of the medulla being filled with air. The function of the medulla is to provide the living fibre with an inner canal for the flow of juices whereby it receives nourishment for its growth. It also adds much to the porosity of the fibre, forming a capillary tube whereby the latter may suck up solutions of various kinds, such as dyestuffs, different salts, etc., allowing these to gradually permeate through the cortical

layer as well. The epidermal layer of scales is rather impervious to the transpiration of solutions, and only permits of their entrance into the fibre at the joints of the scales, so it may be seen that the medulla of the fibre becomes an important adjunct in the chemical treatment of wool in the processes of mordanting, dyeing, and bleaching. It might also be noted, in this connection, that the epidermal scales become but slightly, if at all, dyed when various coloring-matters are applied to the fibre, but remain clear and translucent. Hence it may be readily understood that if two samples of wool are dyed simultaneously, the one consisting of fibres having small and open scales, while the other has a thick and highly resistant epidermis, the resulting color on the two samples will have a different quality or tone, due to the influence on the latter of the uncolored and translucent scales. In wools where this influence is very marked it is almost impossible to obtain rich and full shades of color, due to the transparency and lustre of the surface, which allows of considerable white light being refracted through the fibre along with the reflected color. This also explains the well-known fact that the longitudinal surface of the fibre in many cases presents a different tone of color than the cut ends, the latter usually being richer and deeper in tone; as may be noticed in cut-pile fabrics, such as occur in rugs, plushes, etc. In some cases the epidermal layer, instead of being highly translucent, is opaque and white; this is true of many varieties of coarse wool-hairs, and such fibres as cow-hair, etc. In such instances the dyed fibre will lack liveliness of tone and appear rather dead and flat. The further discussion of this interesting subject must be dealt with in more detail in the study of shade matching. Attention is merely called to it at this point in order to emphasize more clearly the fundamental cause of these differences in color phenomena as lying in the structure of the fibre itself.

Frequently, through disease or other natural causes, the medulla of the wool fibre is imperfectly developed, in consequence of which the wool will not absorb solutions readily, and hence will not be dyed (or mordanted) at all, or only slightly. These fibres, which are known as *kemps*, will occur through the mass

of the wool as undyed streaks, and will give the yarn or fabric a speckled appearance. Not only may this condition, however, be brought about by natural causes, but it may at times be the result of artificial manipulation during manufacturing processes. There is a certain class of wool, for instance, known in trade as *pulled wool*; this is obtained from the pelts of slaughtered sheep, and is usually removed from the skin by the action of lime, the fibres being pulled out by the roots. In the process, the medulla becomes stopped up with solid insoluble particles of lime, which is also true of the end pores of the cortical layer and the joints of the scales. As a consequence, the fibre is very difficult to impregnate with solutions, and will remain more or less completely undyed. This non-porous character is also enhanced, perhaps, by the fact that the fibre does not possess a freshly cut end, but still retains the root, which is more or less rounded off and closed by the coagulation and hardening of the juices in the hair follicle.

The medulla, as a rule, is more developed in beard-hairs than in wool-hairs, and more in coarse grades of wool than in the finer qualities. There also appears to be more or less relation between the breed of the wool and the morphological characteristics of the medullary cells, although this is a subject which as yet has been but little studied. At times the medullary cells exhibit but little differentiation from those of the cortical layers, and these two portions of the fibre become continuous in their appearance, that is to say, no line of demarcation can be drawn between the medulla and the surrounding cortical layer.

In *length*, the wool fibre varies between large limits, not only in different sheep, but also in the same fleece. Generally speaking, the length may be taken as being between 1 and 8 ins. The *diameter* of the fibre is also very variable, even in the same fleece, but may be taken as averaging from 0.004 to 0.0018 in.* According to their length of staple, wool fibres are graded into two classes: *tops* and *noils*. The former includes the longer stapled fibres, which are *combed* and spun into *worsted* yarns, to

* According to Höhnelt, the diameter of sheep's wool varies from 10 to 100 μ (the expression $\mu = \frac{1}{1000}$ mm.); and according to Cramer, the thickness of the hairs from one and the same fleece may vary from 12 to 85 μ .

be manufactured into trouserings, dress-goods, and such fabrics as are not fulled to any extent in the finishing. The latter class consists of the short-stapled fibres, which are *carded* and spun into *woolen* yarns to be used for weft and all classes of goods which are fulled more or less in the finishing operations, where a felting together of the fibres is desired. On comparing worsted and woolen yarns, it will be noticed that the former are fairly even in diameter and the individual fibres lie more or less parallel to each other; whereas in woolen yarns the diameter is very uneven, and the fibres lie in all manner of directions.

The quality of wool obtained from sheep depends very largely on the breed, on climatic conditions, and nature of the pasturage on which the sheep feed. Australia appears to possess the climatic conditions best adapted for wool-growing.* With regard to the nature of the pasturage it has been found that grass from chalky soils gives rise to a coarse wool, whereas that from rich, loamy soils produces fine grades of wool.† As a rule, the sheep

* Other conditions being equal, long droughty seasons in wool-growing districts will cause the fibre to be much shorter than otherwise.

† Utah wools, for instance, are harsh and starchy compared to Wyoming wools. This is due to the alkali in the soil in Utah and the dryness of the climate. The alkali in the soil and the effect which it has upon the water which the sheep drink have a tendency to take the life out of the wool and weaken the staple. The more close and uniform the fibres lie, the better will be the combing qualities of the wool. The Utah wools in this respect are inferior to the Wyomings, Idahos, and Montanas, especially the wools grown in southern Utah. In northern Utah the wools are longer than in southern Utah, but there are very few Utahs either north or south which are fit for combing. The heaviest shrinkage wools generally come from eastern Oregon and Nevada. The degree of shrinkage depends to a considerable extent on the season in which the wools were grown. A wet season and long-continued rains will wash much dirt and dust out of the wools, thus leaving them lighter. The lightest shrinkage wools come from Virginia and Kentucky and the Blue Grass region, where medium wools are grown, where the sheep are cleaner, the range better, and the country hilly, and where comparatively little sand and dirt work their way into the fleece. The shrinkage of washed fleeces ranges from 55% to 35%. Unwashed Indiana wools shrink 38% to 43%. Missouri will shrink around 43% to 45%. Illinois, 45% to 47%. California wools shrink 55% to 72%, depending on the part from which they come. The heaviest shrinkage wools are in southern California, because of the presence of more sand and dirt, and inferiority of the range. Texas spring wools shrink anywhere from 64% to 72%, and the fall wools 58% to 64%. Territory wools shrink from 55% up to 73%. Idahos on the medium order will not shrink over

which yield the best qualities of wool give the poorest quality of mutton.

Unhealthy conditions of the sheep almost always influence the fibre during that period of its growth. If the sheep, for example, is suffering from indigestion, cold, lack of proper nourishment, etc., the fleece during that time will develop tender fibres; when the sheep regains its normal condition of health, the fibre becomes strong again. Thus the fleece may have tender strata through it which will considerably affect the fibre and its uses. These tender spots, of course, render the wool unfit for combing purposes, and it must go into the "clothing" class, and will consequently sell for less money, other things being equal. It is no great injury to the wool, however, aside from spoiling it for combing, as the wool, after it has passed the tender spot, grows fully as well as before the sheep was ill. When sheep have been afflicted with scab, the latter shows itself in tender wool at the bottom of the fibre. The scab leaves a pus-like substance which adheres to the bottom of the fibres and dries there. Vermin on sheep have an influence on the wool; these creatures leave discolorations on the fibre which cannot be removed by scouring. The wool, being "off color," does not sell as well, and, moreover, the fibre is liable to be tender.

As to the amount of wool to be obtained from each sheep, it may be said that the average yield is from 4 to 15 lbs., though in some South American varieties the fleece may weigh as high as

55%. Wyoming wools on the fine and fine medium order shrink 65% to 72%. The Montanas shrink on the average 63% to 69% for fine and fine mediums, and 57% to 60% for mediums. The shrinkage on Arizona wools will range from 66% to 73%, but they will spin to finer counts than the Utah wools, and will scour out very white. In this latter respect the Wyoming wools are superior to any other grown west of the Mississippi River. The shortest wools grown in America are from California and Texas; they are used principally for felts and hats, though they can also be mixed in certain proportions with clothing wool. As the Territory wools are grown mostly in dry climates, they will gain somewhat in weight on being shipped to the Atlantic seaboard and stored for a few months. Utah wools will gain about 1%, Montana wools about $\frac{3}{4}$ %, and Wyoming wools about 1%. The wools from Ohio and other eastern States will not gain anything; in fact, will sometimes show a slight shrinkage. (*American Wool and Cotton Reporter.*)

30 to 40 lbs. With respect to the variation in fibres derived from different kinds of sheep, Bowman gives the following classification:

(1) Those sheep the fibres of whose wool most nearly approach to a true hair, the epidermal scales being most horny and attached most firmly to the cortical structure. This class includes all the lustrous varieties of wool, besides alpaca and mohair.

(2) Those where the epidermal scales, though more numerous than in the first class, are less horny in structure and less adherent to the cortical substance of the fibre. This class includes most of the middle-wooled sheep and half-breeds.

(3) Those where the characteristics of true wool are most highly developed, such as suppleness of fibre and fineness of texture, the epidermal scales being attached to the cortical substance through the smallest part of their length. This class includes all the finest grades of sheep, such as the merino and crosses with it.

CHAPTER III.

THE CHEMICAL NATURE AND PROPERTIES OF WOOL AND HAIR FIBRES.

1. Chemical Constitution.—In its chemical constitution wool is closely allied to hair, horn, feathers, and other epidermal tissues. A distinction must be made between the fibre proper and the raw fibre as it comes from the fleece. In the latter condition it contains a large amount of dirt, grease, and dried-up sweat which have first to be removed by the scouring process before the pure fibre is obtained. Reserving these impurities for a further discussion which does not concern us at this point, and discussing only the fibre itself, it has been found to consist of five chemical elements; namely, carbon, hydrogen, oxygen, nitrogen, and sulphur. Nitrogen is an ingredient common to both wool and silk, but sulphur is distinctly characteristic of wool and hair fibres. To show the average amount of pure fibre to be obtained from raw fleece wool, the following analysis by Chevreul of a merino wool is given:

	Per Cent.
Earthy matter deposited by washing the wool in water. . . .	26.06
Suint or yolk soluble in cold distilled water.	32.74
Neutral fats soluble in ether.	8.57
Earthy matters adhering to the fat.	1.40
Wool fibre.	31.23
	<hr/> 100.00

These figures are based on wool dried at 100° C.; if corrected for air-dry wool containing 14 per cent. of moisture, this would give only about 27.5 per cent. of pure fibre. Of course, the amount of fibre will vary considerably in different qualities and samples of wools, but this figure may be taken as a fair average.

The presence of nitrogen in wool is readily made evident by

simply burning a small sample of the fibre, when the characteristic empyreumatic odor of nitrogenous animal matter will be observed. By heating wool in a small combustion test-tube it will be noticed that ammonia is among the gaseous products evolved, and can be tested for in the usual manner. The presence of sulphur in wool can be shown by dissolving a sample of the fibre in a solution of sodium plumbite (obtained by dissolving lead oxide in sodium hydrate), when a brown coloration will be observed, due to the formation of lead sulphide. On adding hydrochloric acid to the solution and heating, the odor of sulphuretted hydrogen will be distinctly noticed. The application of this test to show the presence of sulphur in wool is sufficient to discriminate chemically between that fibre and those consisting of silk or cotton, and also to detect wool in admixture with other fibres. The older methods of hair-dyeing were based on this same reaction, solutions of soluble lead salts, such as sugar of lead, being applied to the hair, with the result that lead sulphide would be formed and cause a dark brown coloration. The use of such preparations, however, is dangerous, as they are liable to cause lead poisoning.

The presence of sulphur in wool may at times be the cause of certain defects in the dyeing process. In neutral or alkaline baths, if lead is present, the color obtained on the fibre will be more or less affected by the lead sulphide formed on the wool, and serious stains may be the result. The presence of sulphuric acid, however, prevents this, and no staining of the fibre takes place. Stains are sometimes produced when wool is mordanted with stannous chloride, as in the dyeing of cochineal scarlets, due to the formation of stannous sulphide. Occasionally woollen printed goods exhibit brownish stains on the white or light-colored portions after being steamed. These may be due to slight traces of copper or lead being deposited on the cloth during its manipulation and passage through the machines, and these metals when the wool is steamed form dark-colored sulphides which cause the stains. By locally applying a weak solution of hydrogen peroxide such discolorations may be removed without injury to the printed color.

Chevreul recognized the fact that in certain dyeing operations it was necessary to remove the sulphur from wool as far as possible in order to obtain the best results. He accomplished this by steeping the wool in milk of lime and afterwards in a weak bath of hydrochloric acid, and finally washing.

The amount of sulphur existing in wool does not appear to be a very constant factor, but varies in different samples of wool from 0.8 to 4 per cent. The manner in which the sulphur exists in the molecular structure of the fibre is by no means clear, as the majority of it is readily removed without any apparent structural modification of the fibre itself. According to Chevreul, the amount of sulphur in wool was reduced to 0.46 per cent. by several treatments with lime-water. Treatment with a concentrated solution of caustic soda in such a manner as not to disintegrate the fibre (see p. 40) will remove as much as 84.5 per cent. of the sulphur originally present in the wool. On a sample of wool containing 3.42 per cent. of sulphur, treatment in this manner left only 0.53 per cent. of sulphur in the fibre. This would appear to indicate that the sulphur is not a structural constituent of the wool fibre. The fact, however, that the sulphur present is not all removed by even such severe treatment as described would also serve to indicate that this element may exist in wool in two forms, the one an ultimate constituent of the fibre, and the other, and major part, as a more loosely combined compound. The fact that the amount of sulphur naturally present in wool is by no means constant would also tend to support this view; as would also the fact that the major portion of the sulphur is so readily split off to form metallic sulphides. On dissolving wool in boiling caustic soda, it does not appear that all of the sulphur is converted into sodium sulphide, as only about 80 per cent. of it can be obtained as hydrogen sulphide when the caustic soda solution is treated with acid. Probably the remainder of the sulphur exists in the wool as a sulphonic acid, or some compound of a similar nature.

In its chemical nature wool appears to be a *proteoid*, known as *keratin*. As its constituents are not rigidly constant in their proportions, we cannot assign to wool a definite chemical for-

mula. On an average, its composition may be taken as follows:

	Per Cent.
Carbon.....	50
Hydrogen.....	7
Oxygen.....	26-22
Nitrogen.....	15-17
Sulphur.....	2-4

Bowman gives the following analyses of four different grades of English wool:

Constituent.	Lincoln Wool.	Irish Wool.	Northumberland Wool.	South-down Wool.
Carbon.....	52.0	49.8	50.8	51.3
Hydrogen.....	6.9	7.2	7.2	6.9
Nitrogen.....	18.1	19.1	18.5	17.8
Oxygen.....	20.3	19.9	21.2	20.2
Sulphur.....	2.5	3.0	2.3	3.8
Loss.....	0.2	1.0	—	—

These analyses were made of wool which had been purified by extraction with water, alcohol, and ether.

The continued action of boiling water appears to decompose the wool fibre to a certain extent, as both ammonia and hydrogen sulphide may be detected in the gases evolved.

By heating wool to a temperature of 130° C. with water under pressure, the fibre appears to become completely disorganized, and on drying may be rubbed into a fine powder. At higher temperature the fibre is completely dissolved. Based on this fact, Knecht has proposed a method for the carbonization of wool in mixed woollen and silk goods, for the purpose of recovering the silk, as the latter is not materially affected by this treatment. The wool fibre as a whole does not appear to be a homogeneous chemical compound; instead of being a simple molecular body to which a definite formula might be given, it is doubtless composed of several chemically distinct substances. This is evidenced by the fact that the proximate constituents of wool are by no means constant in their amount; furthermore, certain of its constituents are in part removed by simply boiling the fibre in water without a structural disorganization taking place. The

sulphur content is especially liable to fluctuation, and is the most readily removed of the chemical elements of which the fibre is composed; in fact, so easily is some of the sulphur removed as such by various solvents, that it would seem to indicate that this constituent existed in wool either in the free condition or in a compound of exceedingly unstable character.

Schuetzenberger, by decomposing pure wool fibre by heating with a solution of barium hydrate at 170° C., obtained the following decomposition products:

	Per Cent.
Nitrogen (evolved as ammonia).....	5.25
Carbonic acid (separated as barium carbonate).....	4.27
Oxalic acid (separated as barium oxalate).....	5.72
Acetic acid (by distillation and titration).....	3.20
Pyrrol and volatile products.....	1 to 1.50
	C 47.85
Proximate composition of fixed residue, containing leu-	H 7.69
cin, tyrosin, and other volatile products.....	N 12.63
	O 31.83

Williams has shown that by distilling wool with strong caustic potash a large amount of ammonia was obtained in the distillate, together with butylamin and amylamin. Dry distillation of wool yields an oil of a very disagreeable odor, probably consisting of various sulphuretted bases; also a considerable amount of pyrrol and hydrogen sulphide gas, together with a small amount of carbon disulphide, and traces of various oily bases.

The fatty and mineral matters present on the raw wool fibre consist on the one hand of wool grease derived from the fatty glands surrounding the hair-follicle in the skin, and on the other hand, of dried-up perspiration from the sudorific glands in the skin. The wool grease is mostly to be found as the external coating on the fibre* which serves to protect it from mechanical injury and felting while in the growing fleece.† There is also a

* The statement made in some text-books that raw wool when left in the greasy condition is not attacked by moths is erroneous. The personal experience of the author has proved that raw wool is as liable to the depredations of insects as washed and scoured wool.

† Cotted fleeces are those in which the fibres have grown in and amongst each other on the sheep's body so that they form a more or less perfect mat of wool. These mats are hard or soft according to the extent to which the matting process

small amount of oily matter contained in the medullary intercellular structure of the fibre which appears to have the function of acting as a lubricant for the inner portion of the fibre, thus preserving its pliability and elasticity. Wool grease does not appear to be a simple compound, but evidently consists of several oils and wax-like compounds.

Its chief constituent is *cholesterol*, which appears to be one of the higher monatomic alcohols, and is not a glyceride. Analysis shows it to have the formula $C_{26}H_{43}OH$. It is a solid wax-like substance which very readily emulsifies in water. Associated with cholesterol there is also an isomeric body called *ischolesterol*. Besides these solid waxes, wool grease also contains two fats which have been studied by Chevreul to some extent. These are described as follows:

(a) *Stearerin*, a neutral solid fat, melting at $60^{\circ}C$.; contains neither nitrogen nor sulphur; does not emulsify with boiling water, but emulsifies without saponification when boiled with two parts of caustic potash and water; it is soluble in 1000 parts of alcohol at $15.5^{\circ}C$.

(b) *Elairerin*, a neutral fat melting at $15.5^{\circ}C$.; also free from nitrogen and sulphur; it emulsifies with boiling water, and is saponified with caustic potash; it is soluble in 143 parts of alcohol at $15.5^{\circ}C$.

The dried-up perspiration adhering to the raw wool fibre is also called *suint*. It consists principally of the potash salts of various fatty acids, and it is soluble in water, wherein it differs from wool grease. On extraction with water, suint will yield a dry residue of about 140 to 180 lbs. for 1000 lbs. of raw wool.

has been carried on. Cotted fleeces occur mostly in sheep which have been housed; they are seldom found in the territories where the sheep run on the range and are more exposed and hardy. Cotted fleeces indicate a low degree of vitality, and many are to be found in fleece wool from states east of the Mississippi River. They may be caused by sickness or a low state of the blood, or they may be found in an old sheep which is giving out or is run down, which contributes to the frowsy condition of the wool. Cotted fleeces are unfit for combing purposes, as they have to be torn apart, and frequently they are so dense and hard that the fibres can only be pulled apart by the use of special machinery. Badly cotted fleeces are used frequently for braid purposes.

This on ignition will give 70 to 90 lbs. of potassium carbonate and 5 to 6 lbs. of potassium sulphate and chloride, so that the amount of potash salts to be derived from raw unwashed wool may be taken to be about 10 per cent. on the weight of the wool.

Besides the mineral matter existing in the soluble suint, there is also a small amount of mineral matter which appears to form an essential constituent of the fibre itself. It is left as an ash when wool is ignited, and amounts on an average to about one per cent., the majority of which is soluble in water and consists of the alkaline sulphates. The following analysis by Bowman shows the typical composition of the ash of Lincoln wool:

	Per Cent.
Potassium oxide.....	31.1
Sodium oxide.....	8.2
Calcium oxide.....	16.9
Aluminium oxide } Ferric oxide }	12.3
Silica.....	5.8
Sulphuric anhydride.....	20.5
Carbonic acid.....	4.2
Phosphoric acid.....	trace
Chlorin.....	trace

Sheep's wool is nearly always white in color, though sometimes it may occur in the natural colors of gray, brown, or black. The *coloring-matter* in wool appears to withstand the action of alkalies and acids, though it is not especially permanent toward light. It appears to be distributed in the fibre in quite a different manner from that of the artificially applied dyes. The natural coloring-matter appears to be contained particularly in the cells of the cortical layer and the marrow in a granular form, and to occur to a greater extent in the medullary than in the cortical cells. In fibres which are only slightly colored the walls of the cells are almost colorless; though when the fibre becomes very strongly colored the cell-walls also appear to be impregnated with the coloring-matter. In wools which have been dyed, however, the cell-walls are nearly always uniformly colored, in consequence of which the lumen of the fibre becomes less pronounced; whereas, with naturally colored wools, the lumen is usually rendered more distinct through the deposit of coloring-matter.

2. Chemical Reactions.—In its chemical reactions wool appears to exhibit the characteristics both of an acid and a base, and no doubt it contains an amido acid in its composition. The presence of an amido group is evidenced by the formation of ammonia as one of the decomposition products of wool, also by the strong affinity of wool for the acid dyestuffs, or even of its ability to combine with acids in general.

Schuetzenberger has shown that the products of the hydrolysis of wool by baryta-water are analogous to those of albuminoids containing imido groups; the experiments of Prud'homme and Flick also indicate the presence of imido rather than amido groups in wool. The fact that wool absorbs nitrous acid, and combines with phenols, which is supposed to indicate the presence of amido groups, may be explained by the formation of nitrosamines with the imido groups, which would also yield colored derivatives with phenols.

The coefficient of acidity, which is a figure meaning the number of milligrams of caustic potash neutralized by one gram of substance, has been determined for wool, together with a number of other albuminoids, as follows:

Wool.....	57.0	Albumin.....	20.9
Silk.....	143.0	Gelatin.....	28.4
Globulin.....	101.5		

Although the amount of acid absorbed and neutralized by wool may be thus quantitatively determined, the amount of alkali absorbed cannot be so obtained, as wool, though it absorbs alkalis, does not neutralize them.

By treatment with concentrated solutions of caustic soda (80° Tw.) wool absorbs about 50 per cent. of its weight of sodium hydrate from solution. Nor can this alkali be totally removed from the wool by subsequent washing with water alone, but requires a treatment with acid for complete neutralization. Wool so treated exhibits a lessened affinity for basic dyes, showing a probable neutralization to a greater or lesser extent of its acid component.

The amido acid of keratin has received the name of *lanuginic acid*, and has been prepared by dissolving purified wool

in a strong solution of barium hydrate, precipitating the barium by means of carbon dioxide, and after filtering, treating the liquid with lead acetate, whereby the lead salt is obtained. This is decomposed by means of hydrogen sulphide, and the lanuginic acid obtained, after evaporation, as a dirty-yellow substance. Its solution in water yields colored lakes with the acid and basic dyestuffs, and also with the various mordants.

According to Knecht, lanuginic acid possesses the following properties: It is soluble in water, sparingly so in alcohol, and insoluble in ether. Its aqueous solution yields highly colored precipitates with the acid and basic dyestuffs; tannic acid and bichromate of potash also give precipitates. The following mordants in the presence of sodium acetate also give precipitates: alum, stannous chloride, copper sulphate, ferric chloride, ferrous sulphate, chrome alum, silver nitrate, and platinum chloride. Lanuginic acid exhibits all the properties of a proteoid, and may therefore be classed among the albuminoids; it is soluble in water at all temperatures, and its solution is not coagulated. With Millon's reagent and with the double compound of phosphoric and tungstic acids, it shows the characteristic albuminoid reactions. Knecht recommends the use of a solution of wool in barium hydrate for the purpose of animalizing vegetable fibres. Cotton so treated is capable of being dyed with acid and basic dyestuffs.

When heated to 100° C., lanuginic acid becomes soft and plastic, and the majority of its colored lakes also melt at this temperature. It is completely soluble in water at all temperatures and the solution is not coagulated by boiling. It also gives the characteristic albuminoid reactions with Millon's reagent, and the double compound with phosphoric and tungstic acids. Knecht gives the following analysis of lanuginic acid:

	Per Cent.
C.....	41.61
H.....	7.31
N.....	10.26
S.....	3.35
O.....	31.44
	<hr/> 93.97

Though lanuginic acid contains a notable amount of sulphur in its composition, it is not blackened by treatment with sodium plumbite.

When treated with dilute acids, the wool fibre does not appear to undergo any appreciable change; although, from the fact that acids are very readily absorbed by wool and very tenaciously held by it, there is reason to believe that some chemical combination takes place between the fibre and the acid. It can be shown, for example, that if wool be treated with dilute sulphuric acid, all of the acid cannot again be extracted by boiling in water until the wash waters are perfectly neutral; and wool thus prepared has the power of combining with the various acid colors without the necessity of adding any acid to the dye-bath. It is also true, that if wool which has been treated with sulphuric acid is boiled in water, ammonium sulphate is to be found in the solution, showing that some chemical action has probably taken place between the acid and some basic constituent of the wool fibre. Hydrochloric acid acts much in the same manner as sulphuric acid, although the amount permanently absorbed by the fibre is quite small, most of the acid being removed by boiling water. Chromic acid is also absorbed in like manner, and no doubt the usefulness of bichromates as mordants for wool depends somewhat on the chemical combination between the fibre and the chromic acid. With nitric acid wool behaves somewhat differently, for unless the acid be very dilute and the temperature low, the fibre will assume a yellow color, which is probably due to the formation of xanthoproteic acid. Formerly this yellow color was supposed to be due to the formation of picric acid, but this view is erroneous. Nitric acid has a similar effect on the skin, the yellow stains which it produces being a subject of common experience. If the strength of the acid is below 4° Tw., the yellow coloration on wool is not very marked, and in this manner nitric acid has been largely employed as a stripping agent, especially for shoddies.

Richards has shown that by the action of nitrous acid, wool is diazotized in a manner similar to an amido compound, and may be developed subsequently in an alkaline solution of a phenol, giving rise to quite a variety of shades. When wool is treated

in the dark with an acid solution of sodium nitrite (6 per cent.) it quickly acquires a pale-yellow color, rapidly changing on exposure to light. Wool prepared in this manner is turned brown by boiling water, and caustic soda effects the same change, the color becoming yellow again on treatment with acids. Stannous chloride in a warm solution discharges the brown color. Diazotized wool appears to have an increased attraction for basic dyes and a lessened affinity for the acid dyes. Exposure to light bleaches diazotized wool, which is then turned orange by alkalis, and not brown. The following colors may be obtained by treating diazotized wool with various phenols in alkaline solution:

Phenol.	Color.	Reaction with H_2SO_4 .
Resorcin	Orange	Pale red
Orcin	Orange	Pale red
Pyrogallol	Yellowish brown	Orange
Phloroglucin	Bordeaux	No change
α -naphthol	Red	Black
β -naphthol	Red	Pale red

When dyed in connection with metallic mordants, these phenol colors are fast to light, fulling, acids, and boiling water. Tin mordants give yellow and orange shades, aluminium orange, iron dark browns and olive browns, chromium and copper garnet. Wool treated with nitrous acid acquires a harsh feel and is non-hygroscopic.

Its acid number is 169, and its iodine number 4.7, whereas untreated wool has the numbers 88 and 18.4 respectively. It also appears to contain less nitrogen than ordinary wool (*Lidow, Chem. Centr.*, 1901, 1, 703).

Vignon (*Compt. Rend.*, 1890, No. 17) has experimented on the amount of heat disengaged by treating wool with different acids and alkalis, with the following results, using 100 grams of unbleached wool:

Reagent.	Calories Liberated.
Potassium hydrate (normal).....	24.50
Sodium hydrate (normal).....	24.30
Hydrochloric acid (normal).....	20.05
Sulphuric acid (normal).....	20.90

These figures are interesting in indicating the relative acidity and alkalinity of the wool fibre.

In common with most other organic substances, wool is totally destroyed by the action of concentrated mineral acids.

With organic acids, wool is usually reactive, readily absorbing oxalic, lactic, tartaric, acetic, etc., acids. Tannic acid, however, is an exception, and is not absorbed to any extent by the fibre. But if wool is treated in a boiling solution of tannic acid and the latter fixed in the fibre by a subsequent treatment in a solution of tartaric emetic (or other suitable metallic salt), it will be found that the fibre becomes altered in such manner that it no longer exhibits its normal affinity towards acid, substantive, and mordant dyes. Towards basic dyes, however, the affinity of the wool becomes considerably increased by reason of the presence of tannin.

Although so resistant to the action of acids, on the other hand, wool is quite sensitive to alkalies; so much so, in fact, that a five per cent. solution of caustic soda at a boiling temperature will completely dissolve wool in five minutes. From this fact it is easy to understand why soaps, and scouring and fulling agents in general, should be free from appreciable amounts of caustic alkalies. The weaker alkaline salts, such as the carbonates, soaps, etc., are not so destructive in their action, and when employed at moderate temperatures they are not regarded as deleterious, and are largely used in scouring and fulling. With respect to the amount of caustic alkali necessary to decompose wool, Knecht found that on boiling wool for three hours with three per cent. (on the weight of the wool) of caustic soda the fibre was not disintegrated, but on increasing the amount to six per cent., complete disintegration took place and the wool was almost entirely dissolved.

The action of concentrated solutions of caustic alkalies on wool is a rather peculiar one.* Solutions of caustic soda of a strength below 75° Tw. will rapidly disintegrate the fibre, but with solutions of 75°-100° Tw. the fibre is no longer disintegrated, but, on the other hand, increases from 25 to 35 per cent. in tensile strength, becomes quite white in appearance, and acquires a

* Kertesz, *Färber-Zeit.*, ix. 35-36; Buntrock, *Färber-Zeit.*, ix. 69-71.

high lustre and a silky scroop. The maximum effect is obtained by using a caustic soda solution of 80° Tw. and keeping the temperature below 20° C.* The duration of the treatment should not be more than five minutes. The addition of glycerin to the solution of caustic soda renders the action of the alkali more effective. Wool treated in this manner may be said to be "mercerized," though the action of the caustic soda in this case is not quite analogous to that in the mercerization of cotton. From the decrease in the density of the caustic soda solutions employed, it has been shown that the wool absorbs a considerable amount of sodium hydrate from solution. Whether this is held by the wool in true chemical combination has not been ascertained. The treated wool contains but a small amount of sulphur compared with that present in the original fibre (see page 30); analysis, in fact, shows that only about 15 per cent. of the original sulphur remains in the mercerized wool. The dyeing qualities of the latter are also different from the original fibre in that it absorbs more dyestuff from solution and hence yields heavier shades. Quantitative tests have shown that the increase in the absorption of dyestuffs is as follows:

Class of Dyestuff.	Increase, per cent.
Basic.	12.5
Acid.	20.0
Substantive.	25.0
Mordant.	33.3

Mercerized wool also shows an increased absorption with respect to solutions of various metallic salts.

The exact nature of the action of caustic soda under the conditions given is rather difficult to satisfactorily explain. Through a microscopic examination of the treated fibres it appears that the individual scales on the surface of the wool are more or less fused together to a smooth surface, which would account for the great increase in lustre. The additional tensile strength is probably accounted for by the same fact, the closer adhesions of the scales giving a greater rigidity to the fibre. The volatile alkalies,

* Matthews, *Journ. Soc. Chem. Ind.*, XXI. 685.

such as ammonia and ammonium carbonate, do not have any marked deleterious effect on wool, especially at low temperatures; hence these compounds form excellent scouring materials. The hydroxides of the alkaline earths, though less violent in their action than the fixed caustic alkalis, nevertheless decompose wool. Milk of lime, even in the cold, abstracts most of the sulphur, and also causes the fibre to become hard and brittle if the action is prolonged; the wool also loses its felting quality to a considerable extent. Barium hydroxide, as already noted, is used for the decomposition of wool in the preparation of lanuginic acid.

Towards other chemical reagents wool is much more reactive than cotton, and either absorbs from solution or chemically combines with many substances. The fibre is quite readily oxidized when treated with strong oxidizing agents such as potassium permanganate or bichromate, becoming greatly deteriorated in its qualities.

Towards *chlorin* wool acts in a peculiar manner; it is completely decomposed by moist chlorin gas, but in weak solutions it absorbs a considerable amount of chlorin and is strangely altered in its properties.* It becomes harsh,† has a high lustre, and acquires a silk-like feel or "scroop," at the same time losing its felting properties, though its attraction for coloring-matters in general is largely increased.‡

* Bromin appears to have a similar action on wool. It is claimed to have the advantages over chlorin in that it does not turn the material yellow, and that in mixtures of dyed and undyed wool the former is not attacked. This latter statement is open to doubt.

† According to a recent German patent, the harshness of chlorinated wool may be considerably lessened by working the material first in a solution of a salt such as citrate of zinc or acetate of iron, or of sodium stannate or aluminate; this is followed by a second bath of very dilute alkali, after which the goods are exposed to the air. The author, however, has not been able to obtain any satisfactory results on testing this process.

‡ Chlored wool finds quite a number of applications in practice. The process is used, for instance, for the purpose of imparting a silk-like gloss to the fibre. Again, if yarns of chlored wool and ordinary wool are woven together in pattern, and the fabric afterwards fulled, since the chlored wool does not felt it will not shrink up like the remainder of the yarn, and in consequence the pattern will be brought out with very good effect; a great variety of novelties may be produced in this manner. Finally, the property of chlored wool to take up more dyestuff

With *neutral metallic salts* wool does not seem very reactive, as it does not absorb them appreciably from their solutions. With salts, however, which are *acid* in reaction and are capable of being easily dissociated, such as alum, ferrous sulphate, etc., the wool fibre possesses considerable attraction, especially when boiled in their solutions.

With regard to *coloring-matters*, wool is the most reactive of all the textile fibres, combining directly with acid, basic, and most substantive dyestuffs, and yielding, as a rule, shades which are much faster than those obtained on other fibres.

If wool is left in a warm place in a moist condition so that the fibre does not have free access to plenty of fresh air, it will soon develop a fungoid growth or mildew in spots. This causes the fibre to become tender and eventually rot. This fungoid growth will develop without any sizing ingredients or other foreign matter being present on the fibre. It rapidly attacks the scales on the surface of the fibre, and then eats into the inner substance of the wool. Under the microscope (see Fig. 14) this fungoid growth appears as two forms: (a) Small elliptical cells which adhere to the surface of the fibre and spread out from it; they seem to colonize especially at the joints of the scales; (b) a tree-like growth consisting of several cells joined together and branching off from one another; these grow over the fibre as a kind of filmy integument, and do not appear to corrode the wool

than ordinary wool, when dyed in the same bath, is also utilized; and fabrics with beautiful two-color effects may be easily obtained in this manner by weaving the chlored wool into designs with ordinary wool, and afterwards dyeing with suitable coloring-matters.

The chloring of the woolen yarn is carried out in practice as follows: The material is well freed from all greasy matters by a preliminary scouring; this must be very thorough, otherwise good results will not be obtained, as the yarn is liable to finish up very uneven. A steeping in hydrochloric acid next takes place; the solution should be cold and have a density of $1\frac{1}{2}^{\circ}$ Tw. The wool should be left in this bath for twenty minutes. It is next passed into a solution of bleaching powder standing at 3° Tw., and worked for ten minutes; after which it is again treated with the solution of hydrochloric acid, and washed thoroughly. It is said that sodium hypochlorite is better to use than chloride of lime, and sulphuric acid is preferable to hydrochloric, showing less tendency to turn the material yellow. The yellow color due to the chlorin may be removed by treatment with sulphurous acid.

as rapidly as the first kind of cells. Mildew is especially apt to develop on woolen material which contains a small amount of alkali, the alkaline reaction probably being favorable to the growth of the fungus.

Wool is more *hygroscopic* than any other fibre, but the amount of moisture it will contain will vary considerably according to



FIG. 14.—Wool Fibres Attacked by Fungoid Growth (Mildew).

the humidity and temperature of the surrounding atmosphere. Under average conditions, however, it will contain about 14–18 per cent. of absorbed moisture. The hygroscopic quality of wool is a subject of considerable importance in the commercial handling of this fibre, for the weight of any given lot of wool will vary within large limits in accordance with climatic conditions; that is to say, the shipment of wool from one locality to another of different humidity and temperature will cause a loss or gain

in the apparent weight of the material. So important a factor has this become in the commercial relations between wool dealers, that conditioning houses for wool have been established in many European centres for the purpose of carefully ascertaining the actual amount of fibre and moisture present in any given lot of wool, the true weight being based on a certain standard percentage of moisture, or so-called "regain." This percentage varies somewhat with the character of the material and also the conditioning house, ranging from 19-16 per cent. The hygroscopic quality of wool also has an important bearing on the spinning and finishing processes for this fibre, it being necessary to maintain a definite and uniform condition of moisture in order that the best results be obtained in the spinning of yarns and the finishing of the woven fabric. The wool fibre also appears to possess a certain amount of water of *hydration*, which is no doubt chemically combined in some manner with the fibre itself; for it has been observed that wool heated above 100° C. becomes chemically altered through a loss of water at that temperature. This will no doubt explain the fact that air-dried wool is superior in quality to that dried by means of artificial heat, which usually signifies a rather elevated temperature. According to Persoz, the destructive action of high temperatures on the wool fibre may be prevented by saturating the material with a 10 per cent. solution of glycerin, after which treatment the wool may be exposed to a temperature of 140° C. without being affected. The explanation of this action is no doubt to be found in the fact that glycerin holds water with considerable energy, and even at these elevated temperatures all of the moisture originally present in the wool is not driven out of the fibre. In order to economize time, it is sometimes necessary to dry wool rather quickly by the use of suitable machinery and high temperatures. Where a proper regulation of the temperature is possible, the wet wool may be subjected to quite a high degree of heat without injury, for the fibre itself does not become heated up, due to the rapid evaporation of the moisture. As the fibre becomes drier, however, it is important that the temperature fall, so that at the end of the operation, when the wool has become dried to its normal con-

tent of moisture, the temperature should be that of the atmosphere.

Too much importance cannot be attached to the proper drying of wool in all of its stages of manufacture, either in scouring, dyeing, washing, or finishing. If wool is overdried, that is, if the moisture in it is reduced to an amount much less than that which it would normally contain, inferior goods will always be the result, for the intrinsic good qualities of the fibre become greatly depreciated every time such a mistake is committed.

The following table shows the percentage of moisture in air-dried wool and when exposed to an atmosphere saturated with moisture, as compared with the same values for other fibres:

Fibre.	Air-dry.	Saturated.	Fibre.	Air-dry.	Saturated.
Wool.	8-12	30-40	Manila hemp. . . .	12.5	40
Silk.	10-11	30	Jute.	6	23.3
Cotton.	6.66	21	Flax.	4.2-5.7	13.9-24
Ramie.	6.52	18.15			

3. Conditioning of Wool.—In speaking of the hygroscopic quality of wool, it was mentioned that this fibre was capable of absorbing a considerable amount of moisture, and that this amount varied within rather large limits, depending upon the conditions of temperature and humidity of the air to which it may be exposed. It may be readily understood from these facts, that in the buying and selling of wool and woollen goods upon a basis of weight, the question as to how much moisture is present becomes of great practical importance in determining the money value of the operation. In England and on the continent of Europe, this fact has been recognized for some time, and there have been established at the various European wool centres official laboratories where the percentage of moisture in raw wool or in manufactured woollen material is carefully ascertained, and the sales are based on the actual amount of normal wool fibre contained in the lot examined. These official laboratories are called "conditioning houses," and the process of determining the amount of moisture in the wool is termed "conditioning." In the conditioning of wool the operation is carried out as follows: Repre-

sentative samples are taken from the lot under examination; these are mixed together, and three test samples of $\frac{1}{2}$ to 1 lb. each are taken. The test sample, after being carefully weighed, is placed in the conditioning apparatus and dried to constant weight at a temperature of 105° – 110° C. (220° F.). This weight represents the amount of dry wool fibre present in the sample, the loss in weight represents the amount of moisture the wool contained. The amount of normal wool is obtained by adding to the dry weight of the wool the amount of moisture supposed to be present in the air-dried material under normal conditions of humidity and temperature. The added amount is termed "regain," and is officially fixed by the conditioning house. This permissible percentage of regain varies with the form of the manufactured wool; the conditioning house at Bradford, England, for instance, has established the following figures:

	Per Cent.
Wools.	16
Tops combed with oil.	19
Tops combed without oil.	$18\frac{1}{2}$
Noils.	14
Worsted yarns.	$18\frac{1}{4}$

The conditioning house at Roubaix, on the continent, allows the following percentages for regain on woollen materials:

	Per Cent.
Wools.	$14\frac{1}{4}$
Tops.	$18\frac{1}{4}$
Woolen yarns.	17

The method of calculating the amount of normal wool may be illustrated by the following example: A lot of 1000 lbs. of loose wool was submitted for conditioning; ten samples of 1 lb. each were taken from different parts of the lot; these were mixed together and three samples of 250 grams each were taken for testing. On drying to constant weight the three samples lost, respectively, (1) 18.25 per cent., (2) 18.30 per cent., (3) 18.22 per cent., making the loss 18.26 per cent. Hence in the entire lot of 1000 lbs. of wool there were 182.6 lbs. of moisture or $1000 - 182.6 = 817.4$ lbs. of dry wool. The permissible amount of regain in this case was 16 per cent.; hence the normal amount of

wool would be $\left(817.4 \times \frac{16}{100}\right) + 817.4 = 948.2$ lbs. instead of 1000 lbs.

The apparatus to be employed for the conditioning test is usually one of such a construction as to be especially adapted

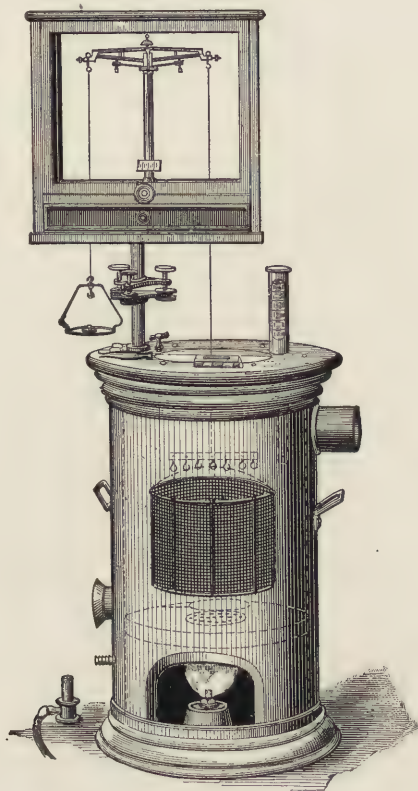


FIG. 15.—Conditioning Apparatus.

for the purpose. The form may differ somewhat in details with different makers, but a typical conditioning oven may be described as follows:

The apparatus consists of an upright oven heated by a flame placed in the lower chamber. An even temperature is maintained by so conducting the currents of heated air that they pass completely around the inner chamber or oven containing the sample to be tested. A thermometer projecting into the oven

from above is employed for indicating the temperature, and this may be maintained at the desired point by a proper regulation of the supply of heat. The material to be conditioned, in whatever form (as loose wool, yarn, etc.), is placed in a wire basket suspended from one arm of a balance fixed outside and above the

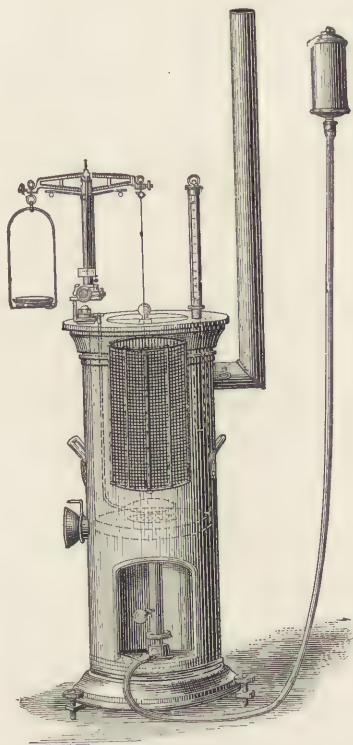


FIG. 16.—Another Form of Conditioning Apparatus.

oven; the weight of the basket and its contents is counterpoised by placing definite weights on a scale-pan suspended from the other arm of the balance. As the material diminishes in weight through the volatilization of its moisture, the loss is noticed from time to time by removing the necessary weights from the scale-pan in order to restore the equilibrium of the balance. When the weight becomes constant after heating at 110° C., the total loss is recorded, and this figure represents the amount of moisture

which was originally present in the material tested. The balance is usually enclosed in a suitable case in order to protect it from draughts of air whereby its sensibility would be impaired.

Another form of conditioning apparatus of somewhat different shape is shown in Fig. 16.

CHAPTER IV.

SHODDY AND WOOL SUBSTITUTES.

BESIDES the natural varieties of wool which find applications in the textile industries, we have a large quantity of regenerated wool employed as a textile fibre. This is obtained by tearing up woollen rags and waste, converting it back into the loose fibre and spinning it over again, either alone, or in admixture with varying proportions of pure fibre or fleece wool. This *artificial wool*, or *wool substitute*, as it is frequently called, is also obtained from rags and waste containing wool and cotton, or even silk; the vegetable fibre being destroyed by chemical treatment, leaving the animal fibre to be extracted and used again. On this account it is sometimes known as *extract wool*. The industry of converting regenerated fibre into yarns and fabrics has assumed of late enormous proportions, and nearly all cheap woollen goods contain a high percentage of these wool substitutes in their composition. Depending on its source of production, this regenerated wool will vary largely in its quality, and according to its origin and nature it is classed under several names, chief among which are the following:

(a) *Shoddy*. Though this name is frequently applied to all manner of regenerated fibre, it is more specifically used to designate that which is derived from all-wool rags or waste which have not been felted, also from knit goods. This yields the best quality of fibre, the average length of which is about one inch. In many cases it is almost equal in quality to a fair grade of fleece-wool, and is used in the production of many high-grade fabrics.

(b) *Mungo* refers to the fibre obtained from woollen material

which has been fullled or felted considerably; to disintegrate the rags the fibres must be torn apart, and consequently it yields fibres of shorter staple and less value than the preceding.

(c) *Extract wool* is that obtained from mixed wool and cotton rags and waste, and has to undergo the process of carbonization whereby the vegetable fibre is destroyed.* It is sometimes called alpaca, and varies much in its length of staple and other qualities. Besides these well-known varieties of regenerated wool there are a number of others to be met with in commerce, such as *Thibet wool*, which is usually obtained from light-weight cloth clippings and waste. *Cosmos fibre* is a very low grade material, usually containing no wool at all, being made by converting flax, jute, and hemp fabrics back to the fibre. Even the short down obtained in the shearing of woollen cloths is used; it being employed as a filler. The process of using it is called "impregnating," and consists in fulling the short waste into the cloth on the under side.

Woolen fibres consisting of shoddy, usually offer a very characteristic appearance under the microscope, sufficient, at least, to distinguish them from fibres of new wool. A sample of shoddy generally shows the presence of other fibres besides wool, and fibres of silk, linen, and cotton are frequently to be observed (Fig. 17). Also, the colors of the different woolen fibres present is frequently quite varied, so that shoddy usually presents a multi-colored appearance under the microscope. A very striking appearance, also, is the simultaneous occurrence of dyed and undyed fibres; the diameters of the fibres will also vary between large limits, the variation in this respect being much more than with fresh wool. Some samples of shoddy will also show a large number of torn and broken fibres; and usually, the external scales are rougher and more prominent.

It must be borne in mind, however, that pure wool may also

* This process is generally carried out by steeping the rags in a solution of sulphuric acid (6° Tw.) at 140° to 180° F., and then drying; whereupon the vegetable fibres are decomposed and are easily dusted out by willowing, whereas the wool fibres are scarcely affected. The excess of acid is then removed by treatment with soda-ash and washing. The fibres obtained are sometimes over one inch in length.

show the presence of small quantities of vegetable fibres at times. These often arise from the occurrence of burrs (bristly and barbed seeds of various plants) in the original fleece. South American wools are especially liable to contain such burrs; in many cases these are incompletely removed, and may ultimately appear even in the woven cloth. This frequently explains the existence of short fibres or vascular bundles of vegetable matter in cloth. Isolated fibres of woody tissue and cotton may also accidentally

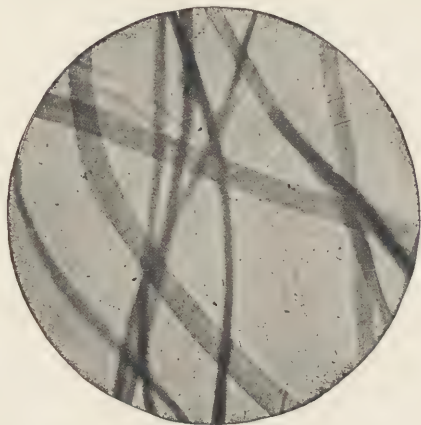


FIG. 17.—Typical Appearance of Shoddy Fibres ($\times 250$).
Showing fibres of various characters and colors.

creep in through a variety of causes. According to Höhnel, samples of pure wool may easily contain as much as $\frac{1}{2}$ per cent. of vegetable fibre. The latter authority also states that the vegetable fibres of shoddy, as a rule, are removed by carbonizing; hence the absence of cotton, linen, etc., must not be taken as a criterion to distinguish between pure wool and shoddy. When, however, cotton (always dyed) or cosmos fibre occurs in at least a quantity of one per cent., this may be taken as a direct indication of the presence of shoddy, as it would scarcely ever happen that pure wool is adulterated with cotton; this only happens by admixture with shoddy-wool. Undyed cotton, unless present in considerable amount, cannot be considered as a suspicious component.

The determination of the length of staple is also a rather unre-

liable indication as to the presence of shoddy, for there are varieties of shoddy-wools which are longer in staple than many fleece-wools; and also woven goods, though composed entirely of fleece-wool, may show the presence of a large number of short fibres caused by the shearing of the surface of the cloth, and also brought about by tearing of the fibres in heavy pulling.

Where woolen cloth has been impregnated or filled with short fibres obtained from clippings, such may usually be recognized by teasing the sample out with a stiff bristle-brush. Good cloth should not yield over $\frac{1}{2}$ per cent. of clipped fibres from both sides. When the amount of such fibres is at all considerable, they may be used as serviceable material to test microscopically for shoddy, as they are most likely to be made up of this character of wool.

Fine fleece-wools hardly ever show the absence of epidermal scales (though this is frequently the case with coarse wools); hence if examples of such fine wools are found showing a lack of epidermis, it may usually be taken as an indication of shoddy.

Höhnel, however, calls attention to the fact that the following conditions previous to the manufacturing process itself have considerable influence on the good structure and integrity of the wool fibre: badly cut staple, lack of attention in raising the sheep, poor pasturage, sickness of the animal, the action of urine, snow, rain, dust, etc., packing the wool in a moist condition, rapid and frequent changes of moisture and temperature, the use of too hot or too alkaline baths in scouring, scouring with bad detergents, etc. These influences may lead to the partial removal of the epidermis, and to the softening and breaking of the ends of the fibre. There must also be considered the influence of wil-
lowing, carding, combing, spinning, weaving, gigging, fulling, acidifying, washing, shearing, pressing, etc., from which it is easy to understand why even fleece-wool may show the entire absence of epidermis. Höhnel also criticises other alleged characteristics of shoddy, such as torn places in the fibre, unevenness in diameter, etc., claiming that these can hardly be taken as an indication of shoddy, because such marks are often regularly present in many fleece-wools. Most samples of shoddy, in

fact, show scarcely any structural differences from ordinary fleece-wool. The ends of shoddy fibres, however, usually present a torn appearance; at least there is a great predominance of such fibres in shoddy, whereas in fleece-wool this appearance is seldom to be observed, the end of the fibre being cut off sharply. The appearance of the torn fibres may be easily observed under the microscope; the epidermis being entirely torn away, as well as the marrow which is sometimes present, while the fibrous cortical layer is frayed out like the end of a brush. This appearance can usually be rendered more distinct by previously soaking the fibres in hydrochloric acid. Sheared fibres are recognized by being very short and by having both ends sharply cut off.

The color of the fibres is also a characteristic appearance of shoddy, as the majority of shoddy is made up of variously colored wools. It is of rare occurrence that rag-shoddy possesses a single uniform color. Hence if a sample of yarn, possessing a single average color, on examination reveals the presence of variously colored fibres, it is almost a positive indication of shoddy. In this connection it must not be forgotten, however, that frequently differently colored wools are mixed together previous to spinning, to make so-called "mixes." As a rule, however, only two to three colors are used together; therefore a purposely mixed yarn of this description is not likely to be confounded with a shoddy yarn where individual fibres of a large number of colors are nearly always shown.

CHAPTER V.

OTHER HAIR FIBRES.

1. BESIDES the fibre obtained from the domestic sheep, there are large quantities of hair fibres employed in the textile industries and obtained from related species of animals, such as goats, camels, etc. As these are all more or less utilized in conjunction with wool itself, and are subjected to similar operations in manufacturing, it will not be out of place to consider them at this point. The chief among these related fibres are mohair, cashmere, alpaca, cow-hair, and camel's hair.

2. **Mohair.**—This fibre is obtained from the Angora goat, an animal which appears to be indigenous to western Asia, being largely cultivated in Turkey and neighboring provinces. The fleece is composed of very long fibres, fine in staple, and with little or no curl. The fibre is characterized by a high silky lustre. Mohair is now grown to a considerable extent in the Western States, principally Oregon, California, and Texas, the goats having originally been imported from Turkey; there is also a large quantity of mohair grown in Cape Colony. The principal mohair clips (1902) are as follows:

Turkey.....	8,500,000 lbs.
Cape Colony.....	7,500,000 "
United States.....	1,250,000 "

The principal use of mohair is for the manufacture of plushes, braids, fancy dress fabrics, felt hats, and linings. The character of fabric in which it may be employed is rather limited on account of the harsh wiry nature of the mohair fibre, and the fact that it will not felt to any degree. Domestic mohair (Ameri-

can) has only about two-thirds of the value of the foreign fibre; mohair in general has quite a large amount of kempy fibre (which will not dye), but the domestic variety contains about 15 per cent. more kemp than the foreign, hence the lower value of the former. Another reason for this lessened value is that foreign mohair always represents a full year's growth (the fibres being 9 to 12 ins. in length), whereas a great deal of domestic mohair is shorn twice a year. This is especially true of that grown in Texas: the hair commences to fall off the goats in that district if allowed to grow for the full year. In judging of the quality of mohair, the length and lustre are of more value than the fineness of staple. The finest grades of domestic mohair come from Texas, that from Oregon and California being larger and coarser. In Oregon the fleece is grown for a full year, and consequently the fibre is very long. The average weight of the fleece from Oregon goats is 4 lbs., while in Texas it is only 2½ lbs. Foreign mohair varies much in quality, depending upon the district in which it is grown; as a rule, the finer varieties are shorter in staple, the finest being about 9 ins. in length. Foreign mohair can be spun to as high a count as 60's, whereas the finest quality of domestic mohair can only be spun to as high as 40's. The coarsest varieties of mohair are used in carpets, low-grade woolen fabrics, and blankets.

Microscopically, the mohair fibre is possessed of the following characteristics: The average length is about 18 cm., and the diameter about 40 to 50 μ , and very uniform throughout the entire length. The epidermal scales can only be observed with difficulty, as they are very thin and flat, though regular in outline. They are also very broad, a single scale frequently surrounding the entire fibre; the edge of the scale is usually finely serrated. The best grades of fibres show no medulla, but there are usually to be found (especially in domestic mohair) coarse, thick fibres possessing a broad medullary cylinder, thus resembling the structure of ordinary goat-hair, from which, however, they are to be distinguished by being more slender and more uniform in their diameter. Longitudinally, the fibre exhibits coarse, fibrous striations, approximating the appearance of broad and regularly occurring fissures (see Fig. 18). Due to the fact that the surface scales

lie very flat and do not project over one another, the edge of the fibre is very smooth, showing scarcely any serrations at all, which accounts for its utter lack of felting qualities. The outer end of the fibre is either slightly swollen or blunt, but never pointed. When viewed under polarized light the fibres occasionally show the presence of a medullary canal, which appears as a hollow space, giving an illumination somewhat resembling that of a



FIG. 18.—Mohair Fibres ($\times 350$).
Showing fine, smooth scales and straight edges.

bast fibre, and covering from one-fourth to one-half of the diameter.

3. **Cashmere** is remarkable for its softness and is much used in the woolen industry for the production of fabrics requiring a soft nap. Cashmere is the fibre employed in the manufacture of the famous Indian shawls. There are two qualities of cashmere wool, the one consisting of the fine, soft down-hairs, and the other of long, coarser beard-hairs. The former are $1\frac{1}{4}$ to $3\frac{1}{2}$ ins. in length and $13\ \mu$ in diameter, while the latter are $3\frac{1}{2}$ to $4\frac{1}{2}$ ins. in length by 60 to $90\ \mu$ in diameter. The down-hairs show visible scales but no definite medulla, whereas the beard-hairs possess a well-developed medulla. The cortical layer is coarsely striated, and shows characteristic fissures. At the point of the

fibre the epidermal scales are either entirely absent, or are so thin as to be scarcely visible. The fibre is very cylindrical; the scales have their free edge finely serrated, and the edge of the fibre also presents the same appearance.

Besides mohair and cashmere, the hair of the ordinary goat is also used at times. It has the following characteristics (Höhnel): It is white, yellow, brown, or black in color, and generally 4 to 10 cm. long. It consists almost entirely of wool-hairs, which, like pulled wool, nearly always show the hair root. The average hair exhibits the following structure (see Fig. 19): At the base

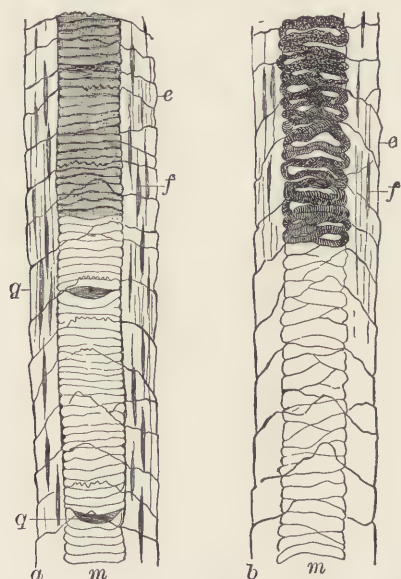


FIG. 19.—*a*, Cow-hair; *b*, Goat-hair. (Höhnel.)

g, characteristic fissures in marrow; *m*, marrow or medulla filled with air;
f, fibrous fissures; *e*, tile-shaped scales.

it is about 80 to 90 μ thick; the root is about $\frac{1}{3}$ mm. long; the marrow is just visible at the root, then rapidly increases in thickness, so that a few millimeters from the base it is 50 μ thick, where the thickness of the hair amounts to 80 to 90 μ . The cortical layer from this point on forms a very thin cylinder. The cross-section is round; the epidermis consists of broad scales about 15 μ long, the forward edges of which are scarcely thickened,

but appear as if terminated by a sharp line; furthermore they are not serrated. The medullary cells are thick-walled, narrow, and flattened. Towards the end the hair is very brittle and easily broken. Colored goat-hair shows the presence of pigment matter in all of its tissues; in such fibres the marrow appears black.

4. **Alpaca**, and its varieties *Vicuna* and *Llama*, have the disadvantage of being mostly colored from brown to black. Though largely used in South America for the production of various fabrics, they do not find much application in the general textile industry. There is another product in trade which goes by the name of vicuña (French *vicogne*), which must not be confused with the true South American fibre, it being simply a trade-name for a mixture of cotton and wool. The name alpaca is also given to a variety of wool substitute. The South American wools often give rise to wool-sorter's disease to those handling them. This disease is anthrax and is caused by the presence of a certain microbe in the fibre. Wool-sorter's disease is caused by *Bacillus anthracis*, which may enter the system either by the skin (through the medium of an abrasion or cut) or by the internal organs, being introduced with the food. In the former case it gives rise to pustules, which become painful and cause excessive perspiration, fever, delirium, and sundry disorders. In the latter case it gives rise to the most serious results, leading to blood-poisoning and inflammation of the lungs, which often prove speedily fatal.

True alpaca is obtained from the cultivated South American goat, *Auchenia paco*. It occurs in all varieties of colors from white, through brown, to black. The reddish-brown and not the white variety, however, is the most valuable. Like other goat-hairs, alpaca consists of two varieties of fibres, a soft wool-hair and a stiff beard-hair. The wool-hairs of the reddish-brown variety are from 10 to 20 cm. in length, and from 12 to 55 μ in diameter (see Fig. 20). The fibre is very smooth, the serrations on the edge being faint and indistinct; the diameter is also very uniform, and there are coarse brown longitudinal striations, but no medulla. The wool-hairs of the white variety are very dis-

tinctly serrated on the edge, and the fibre is not so uniformly thick. The beard-hairs of the brown variety are comparatively few in number, are 5 to 6 cm. in length and about $60\ \mu$ in diameter, and the latter is very uniform. A very broad continuous medullary cylinder is present, 45 to $50\ \mu$ wide; the medullary cells

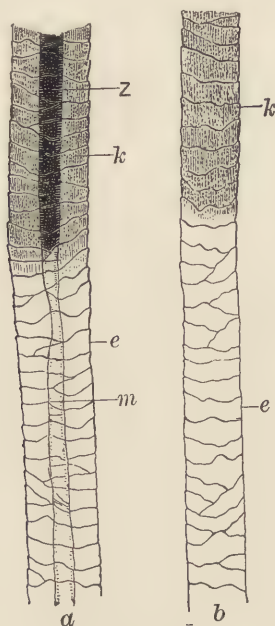


FIG. 20.—Fibres of Alpaca. (Höhncl.)

a, beard-hair containing medulla; *b*, wool-hair free from medulla; *e*, cusp-like scales, thin and broad; *k*, granulated streaks on the fibrous layer; *m*, medullary cylinders; *z*, small medullary cells.

are very indistinct, but are filled with coarse granules of matter. The cortical layer shows occasional fissures, and the brown coloring-matter is principally distributed through the external cortical layer, though very irregularly. The beard-hairs of the white variety also occur rather sparingly; they are 20 to 30 cm. in length and $35\ \mu$ in thickness at the lower end and about $55\ \mu$ towards the upper end. The medulla is broad and continuous, and nearly always filled with a coarsely granulated matter of a gray color. The medulla consists of a single row of short cylin-

drical cells, but as the walls are very thin, the cells are to be seen only with difficulty. The cortical layer is coarsely striated and frequently shows fibrous fissures; the edge of the fibre is not sharply serrated.

5. **Vicuña Wool** (or *Vicogne*) is another South American product obtained from *Auchenia viccunia*, the smallest of this general class of goat-like camels. It is not a cultivated animal, and is evidently disappearing; hence the fibre is not met with in trade to any great extent at the present time. It is a soft, delicate fibre, usually of a reddish-brown color, and much resembles alpaca. It also shows the presence of a fine under-hair and a coarse upper-hair; the former is 10 to 20 μ in diameter, while the latter is 75 μ wide. The scales of the under-hair are very regular and rather easy to distinguish, but generally no medulla is to be seen. The cortical layer is finely striated and frequently contains fibrous fissures. The upper-hairs, however, show a well-developed medulla, mostly dark in color. The fibres of the under-hair are very uniform in diameter and about 20 cm. in length.

An artificial wool substitute also goes by the name of vicuña or vicogne yarn, but bears no resemblance to the true South American fibre. It consists principally of a mixture of cotton with sheep's wool, but is frequently mixed more or less with wools and coarse beard-hairs of poor spinning qualities obtained from various goats (of Asia Minor), from camels, and from South American wools. It is of poor quality and generally yellowish brown in color. It is only used for felted materials or for very coarse fabrics.

6. The **Llama** fibre exhibits scarcely any visible scales, but has well-developed isolated medullary cells. It also consists of two classes of fibres, both of which show longitudinal striations. The under-hair is 20 to 35 μ in diameter, while the upper-hair averages 150 μ . The llama wool comes from the *Auchenia llama*, a cultivated animal. The wool from another variety, *Auchenia huanaco*, is used to some extent in South America, though it seldom appears as such in general trade. This latter animal is not cultivated, but is hunted wild, and is gradually disappearing. Huanaco and llama are nearly always mixed more or less with

alpaca and brought into trade under the latter name. There is but little difference to be found among these three fibres, owing to the close relationship of the animals from which they are derived, and more especially as different portions of the fleece from all varieties of *Auchenia* give wools of entirely different quality with respect to color, fineness of staple, and purity from coarse stiff hairs; and the corresponding portions from the different animals are usually graded together.

7. Camel's Hair is used to quite an extent in clothing material, and is characterized by great strength and softness. It has considerable color in the natural state, which does not appear capable of being destroyed by bleaching; hence camel's hair is either used in its natural condition or is dyed in dark colors. There are two distinct growths of fibre on the camel: the under-hair, which is a fine soft fibre, largely employed for making Jäger cloth; and the upper- (or beard-) hair, which is much coarser and stiffer, and is mostly used for carpets, blankets, etc. Both fibres show faint markings of scales on the surface and well-developed longitudinal striations. The upper-hair always exhibits the presence of a well-defined medulla, which is large and continuous, while the under-hair either shows only isolated medullary cells or none at all. The diameter of the under-hair is from 14 to 28 μ , while the upper-hair averages 75 μ (see Fig. 21). The under-hairs are about 10 cm. in length, are rather regularly waved, and are usually yellow to brown in color; while the others are from 5 to 6 cm. long, and are dark brown to black in color. The epidermal scales of the latter are quite rough, which gives the edge of the fibre a saw-toothed appearance. The presence of large spots, or moles, of brown coloring-matter, especially in the medulla, is quite characteristic. These are usually granular in form. The beard-hairs of the camel are to be distinguished from corresponding cow-hairs by smaller diameter, thicker epidermis, and narrower medullary cells with thicker walls, which are generally darker in color than the enclosed pigment-matter.

8. Cow-hair is extensively employed as a low-grade fibre for the manufacture of coarse carpet yarns, blankets, and a variety of cheap felted goods. It is seldom used alone, however, on

account of its short staple. It comes principally from Siberia. The diameter of cow-hair varies from 0.084 to 0.179 mm. and the length from $1\frac{1}{2}$ –5 cm. The fibres occur in a variety of colors, including white, red, brown, and black. In its microscopic appearance the surface of the fibre is rather lustreless; the ends are very irregular, being blunt and divided. The medullary canal is well marked, occupying about one-half the diameter at the base and tapering towards the free end where it occupies only one-fourth the diameter. Isolated medullary cells are also of frequent

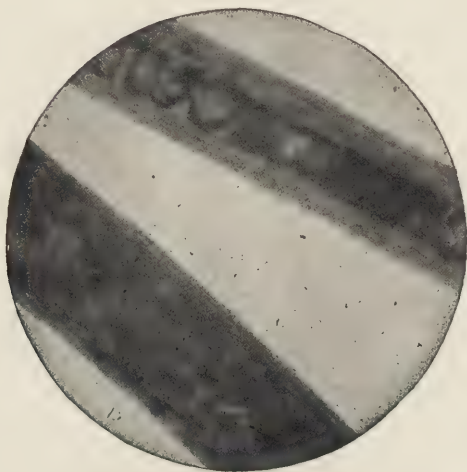


FIG. 21.—Camel's Hair ($\times 500$).

Showing one fibre colored and opaque, with no evidence of structure beyond a striated surface; and a second fibre with well-defined medullary cells.

occurrence. Cow-hair (including also calf-hair) nearly always shows the hair-root, as the fibres are removed from the hide by liming and pulling.

Cow-hair nearly always shows the presence of three kinds of fibres:

(1) Thick, stiff beard-hairs from 5 to 10 cm. in length, and retaining a long narrow hair follicle; above this is the neck of the hair, containing a medullary cylinder consisting of a single series of cells as well as isolated medullary cells. At this part of the fibre the epidermal scales are very thin and broad, and the

forward edges present a serrated appearance; the neck of the hair is about $120\ \mu$ in thickness. Above this the hair rapidly increases to about $130\ \mu$ in thickness, and the medullary cylinder becomes broad ($75\ \mu$) and consists of narrow brick-shaped elements, arranged one on top of the other. The cortical layer is finely striated, the epidermis is indistinct, and the edge of the fibre is smooth. The medullary cells are very thin-walled and contain a considerable amount of finely granulated matter. Towards the pointed end the fibre becomes colorless, and shows distinct fibrous fissures; the medullary cylinder disappears, but the epidermis is not altered. The chief difference between these hairs and the beard-hairs of the goat is that in the former the medullary cells consist of only a single series, and are very thin-walled, and are also frequently isolated from one another, while they are filled with finely granulated matter.

(2) Soft, fine, beard-hairs possessing the same general structure as the foregoing, but not so thick; the neck of the hair being $75\ \mu$ in diameter and not possessing any medulla. Above this the medullary cylinder consists of very thin-walled cells arranged in isolated groups; the epidermal scales overlap one another and are almost cylindrical, are narrow, and with finely serrated edges. About 1 cm. from the base the medullary cylinder becomes discontinuous and breaks up into isolated medullary cells, which continue until the middle of the fibre is reached where they disappear completely; towards the pointed end of the fibre, they reappear and again become a continuous cylinder, consisting of only a single series of cells, however. These are well filled with dark medullary substance.

(3) Very fine soft wool-hairs, free from medulla, and at most only 1 to 4 cm. in length, and frequently only $20\ \mu$ in thickness. The epidermal scales are rough, causing the edge of the fibre to be uneven and have a serrated appearance. The hairs also show frequent longitudinal fibrous fissures.

Calf-hair has the same general structure and appearance, though there is a greater amount of soft wool-hairs present.

9. Minor Hair Fibres.—*Horse-hair* has a diameter of 80 to $100\ \mu$, and a length of 1 to 2 cm. (see Fig. 22). Like cow-hair, it

also occurs in a variety of different colors. Horse-hair is more lustrous than the foregoing, however, and though when viewed under the microscope the ends of the fibre are irregular and often forked, they taper off to points. The medullary cylinder is rather large, occupying about two-thirds of the diameter at the base of the fibre, and tapering to about one-fourth of the diameter at the free end. The medulla consists of one to two rows of very narrow leaf-shaped cells. Isolated medullary cells are of frequent occurrence, especially at the point. The cortical layer frequently contains numerous short orifices or fissures. These remarks refer to the body-hairs of the horse; the hairs of the tail and mane are much longer, reaching from several inches to a foot or more. They find little or no use in ordinary textiles, but are much used as stuffing materials in the manufacture of upholstery.

Cat-hair varies in diameter from 14 to 34 μ , and in length from 1 to 2 cm. The fibres occur in a variety of colors, and have a good lustre. The ends are quite regular and very pointed. The medullary canal contains a single series of regular cells occupying one-half to three-fifths of the diameter of the fibre. The cortical layer is well developed, and its inner face is grooved so as to fit over the medullary cells. There is a thin irregular epidermis which envelops the fibre (see Fig. 23).

Rabbit-hair fibres are usually light brown in color, and measure from 34 to 120 μ in diameter, and from 1 to 2 cm. in length. The medullary canal is filled with several series of cells, quadrangular in shape and with thin walls. They are also arranged in a very regular manner. By careful observation, spiral striations may be noticed on the finer fibres. The epidermal scales are very thick and their forward edges terminate in a sharp point

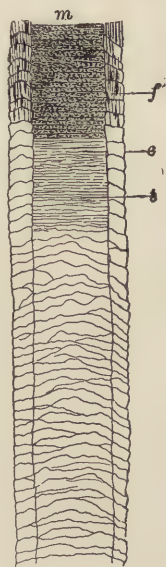


FIG. 22.—Horse-hair.
(Höhncl.)

m, broad medullary cylinder; *t*, thin-walled cells of same; *e*, epidermal scales; *f*, fibrous fissures.

(see Fig. 24). Each scale is placed cornucopia-like into the next lower one, and is drawn out into 1 to 3 large waves. At the base of the fibre the medulla consists of a single row of cells, above

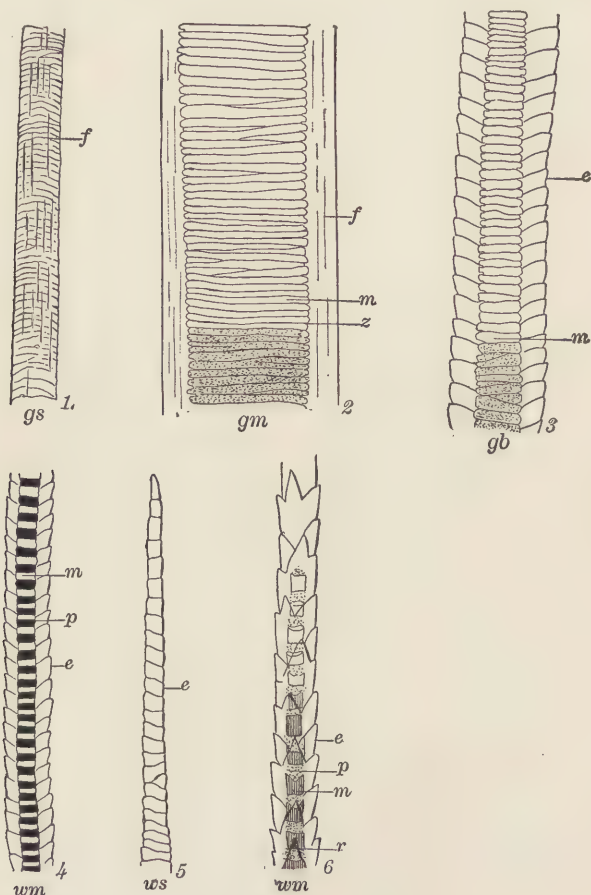


FIG. 23.—Hairs of Cat. (Höhncl.)

1 to 3, beard-hairs; 4 to 6, wool-hairs; *gs*, near the end of hair; *gm*, middle of hair; *gb*, near base of hair; *wm*, middle of wool-hair; *ws*, point of wool-hair; *f*, fibrous fissures; *m*, medullary cells; *z*, serrated edge of medulla; *r*, tooth-like formation of epidermal scales.

the middle this increases to 2 to 4 rows, and farther along the fibre the number of rows of cells increases up to 8, when the hair becomes very wide. Like most pelt-hairs, the fibres are somewhat

flattened at the base, and quite so at their broadest part. The cortical layer is only apparent towards the point where the medulla ceases. The wool-hairs of the rabbit are much thinner than the

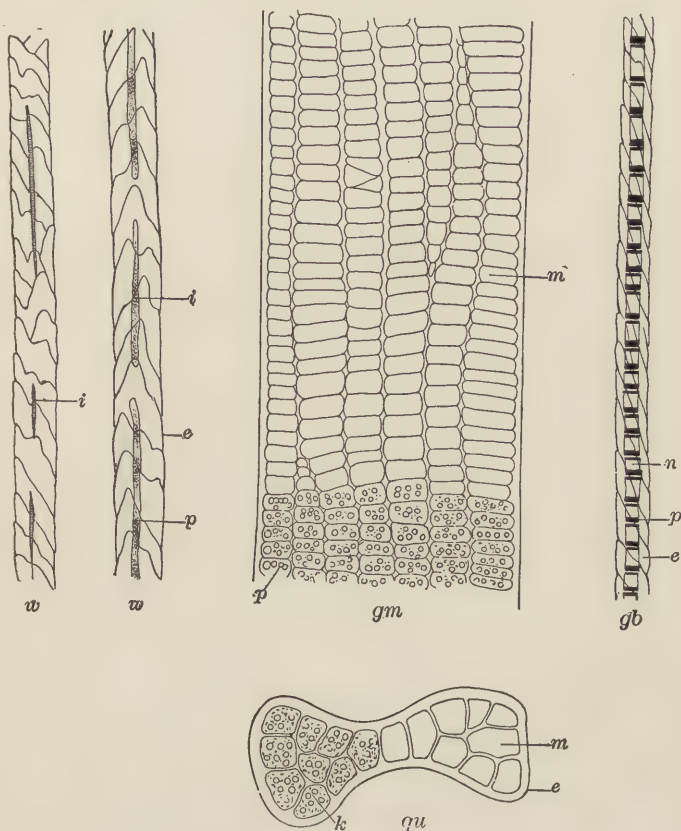


FIG. 24.—Hair of Rabbit. (Höhnel.)

w, wool-hairs; *gm*, middle and broadest part of beard-hair; *qu*, cross-section of beard-hair; *gb*, base of beard-hair; *e*, cusp-like scales; *i*, medullary islands; *m*, *n*, medullary cells with granular contents; *p*, *k*, pigment plate-like cells.

above, the greatest thickness being about 20 μ . Otherwise they correspond in structure to that part of the above fibre near the base.

CHAPTER VI.

SILK: ITS ORIGIN AND CULTIVATION.

1. THE silk fibre consists of a continuous thread which is spun by the silkworm. The worm winds the fibre around itself in the form of an enveloping cocoon before it passes into the chrysalis or pupal state. The cocoon is ovoid in shape and is composed of one continuous fibre, which varies in length from 350 to 1200 meters (400 to 1300 yards), and has an average diameter of 0.018 mm. In the raw state the fibre consists of a double thread cemented together by an enveloping layer of silk-glue, and is yellowish and translucent in appearance. When boiled off or scoured these double threads are separated, and the silk then appears as a single lustrous almost white fibre. Unlike both wool and cotton, silk is not cellular in structure, and is apparently a continuous filament devoid of structure. Höhnelt, however, believes that the silk fibre is not so simple in structure as it is at first believed. The surface of the fibre frequently shows faint striations, which may be rendered more apparent by treatment with chromic acid. Also by saturating the silk with moderately concentrated sulphuric acid and drying, then heating to 80° to 100° C., the fibre will be disintegrated into small filaments, which would seem to indicate that it was made up of a number of minute fibrils firmly held together.

The silkworm is a species of caterpillar, and though there are quite a number of these which possess silk-producing organs, the number which secrete a sufficient quantity of the silk substance to render them of commercial importance is rather limited. The true silkworms all belong to the general class *Lepidoptera*,

or scale-winged insects, and more specifically to the genus *Bombyx*. The principal species is the *Bombyx mori*, or mulberry silkworm, which produces by far the major portion of the silk that comes into trade. The silk industry appears to have had its origin in China, and historically it dates back to about 2700 years B.C. In its early history it is said that the art of cultivating the silkworm and preparing the fibre for use was a strictly guarded secret known only to the royal family. Gradually, however, it spread through other circles and soon became an important industry distributed universally throughout China. The Chinese monopolized the art for over three thousand years, but during the early period of the Christian era, the cultivation of the silkworm (or sericulture) was introduced into Japan. It also gradually spread throughout central Asia, thence to Persia and Turkey. In the eighth century, the Arabs acquired a knowledge of the silk industry, which soon spread through all the countries influenced by the Moorish rule, including Spain, Sicily, and the African coast. In the twelfth century we find sericulture practised in Italy, where it slowly developed to a national industry. In France sericulture appears to have been introduced about the thirteenth century, but it was not until the reign of Louis XIV that it assumed any degree of importance. In more recent times experiments have been made on the cultivation of the silkworm in almost every civilized country.*

According to the number of the generations they produce in a year, the *Bombyx mori* are divided into two classes: the members of the one reproduce themselves several times annually, and are termed polyvoltine; their cocoons are small and coarse. The other worms have only one generation in a year, and hence are termed annual. The cocoons of the latter are much superior to those of the preceding. The cultivation of the silkworm starts with the proper care and disposition of the eggs. With the annual worms there elapse about ten months between the time the eggs are laid and their hatching. The hatching only takes place after the

* Mr. Samuel Whitmarsh, about 1838, appears to have been about the first to attempt sericulture in America. He cultivated the *Motus multicaulis* in Pennsylvania, but the experiment proved to be a failure.

eggs have been exposed to the cold for some time and are subsequently subjected to the influence of heat. When the eggs are laid by the silk-moth they are received on cloths, to which they stick by virtue of a gummy substance which encloses them. For the first few days they are hung up in a room, the air of which is kept at a certain degree of humidity—about semi-saturation. Then comes a period of hibernation, during which the eggs are kept in a cool place; at present artificial refrigeration is resorted to in many establishments. The period of hibernation lasts about six months. After this comes the period of incubation, in which the embryo is gradually developed into a worm and the egg is hatched. The hatching usually takes place in heated compartments in which the temperature is carefully regulated. The period of incubation occupies about thirty days, though this time has been shortened considerably by certain artifices, such as the action of electric discharges. Twenty-five grams of eggs will yield about 36,000 worms on hatching. The caterpillar, on first making its appearance, is about 3 mm. long, and weighs approximately 0.0005 gram. Its growth and development proceeds with extraordinary rapidity, and during its short existence it undergoes a number of very curious transformations. Under normal conditions there elapse thirty-three to thirty-four days between the time of the hatching of the egg and the commencement of the spinning of the cocoon. During this time the worm sheds its skin four times, and these periods of moulting divide the life-history of the worm into five periods. Almost immediately after being hatched the worms devour mulberry leaves with great avidity, and continue to eat throughout the five periods; though when about to shed their skins they stop eating for a time and become motionless. The size and weight of the caterpillars increase with remarkable rapidity; during the fifth period they reach their greatest development, measuring 8 to 9 cm. in length and weighing 4 to 5 grams; and after thus maturing they begin to diminish in weight. The following table by Vignon shows the relative weights of the silkworm during the different stages of its existence. The figures refer to the weight of 36,000 worms:

	Grams.
Eggs.....	25
Worms (36,000).....	17
First period (5 to 6 days).....	255
Second period (4 to 5 days).....	1,598
Third period (6 to 7 days).....	6,800
Fourth period (7 to 8 days).....	27,676
Fifth period (11 to 12 days).....	161,500
At maturity.....	131,920
Cocoons.....	76,250
Chrysalis alone.....	66,300
Butterflies, half of each sex.....	99,865

Thus we see that in less than forty days the weight of the silkworm increases almost 10,000 times.

When the worm has reached the limit of its growth, it ceases to eat, and commences to diminish in size and weight. The time is now ready for the spinning of its cocoon; the worm perches on the twigs so disposed to receive it and exudes a viscous fluid from the two glands in its body wherein the silk secretion is formed. The liquid flows through two channels in the head of the worm, into a common exit-tube, where also flows the secretion of two other symmetrically situated glands which cements the two threads together. Consequently the thread of raw silk is produced by four glands in the worm; the two back ones secrete the fibroin which gives the double silk-fibre, while the two front glands secrete the silk-glue or sericin which serves as an integument and cementing substance. On emerging from the spinneret in the head of the worm, the fibre coagulates on contact with the air.

The worm weaves this thread around itself, layer after layer, until the cocoon or shell is gradually built up. It requires about three days for the completion of the cocoon. After finishing the winding of its cocoon, the enclosed silkworm undergoes a remarkable transformation, passing from the form of a caterpillar into an inert chrysalis or pupa, from which condition it rapidly develops into a butterfly, which then cuts an opening through the cocoon and flies away. As the integrity of the cocoon-thread would be destroyed by the escape of the butterfly, and hence lose much of its value, it is desirable that the development of the chrysalis be stopped before it proceeds too far, and this is accom-

plished by killing it by a heat of 70 to 80° C. or by live steam. The cocoons at this stage weigh from 1.25 to 2.5 grams each, and of this 15 to 16 per cent. is silk fibre. Of this amount, however, only 8 to 10 per cent. is available for silk filaments, the remainder, 6 to 7 per cent., constituting waste and broken threads, and is utilized for spun silk.* As to the thickness of the filaments of silk in the cocoon, Haberlandt furnishes the following data:

Species.	Exterior Layer of Cocoon.	Middle Layer.	Interior Layer.
Yellow Milanais.....	0.030 mm.	0.040 mm.	0.025 mm.
Yellow French.....	0.025 "	0.035 "	0.025 "
Green Japan.....	0.030 "	0.040 "	0.020 "
White Japan.....	0.020 "	0.030 "	0.017 "
Bivoltin worms.....	0.025 "	0.035 "	0.020 "

* There are several different varieties of waste silk, as follows:

1. The refuse obtained in raising the silkworm, called Watt silk in commerce. Owing to the scientific methods of silk-culture in Europe, the amount obtained from this source is very small. China, however, exports a large amount yearly. This material contains about 35 per cent. of pure silk, and is the poorest grade of waste silk on account of its irregularity.

2. The irregularly spun and tangled silk on the outside of the cocoon, called floss silk or Frisons. It comprises from 25 to 30 per cent. of the entire cocoon, and is valuable owing to its purity and fine quality.

3. The residue of the cocoon after reeling; this forms an inner parchment-like skin, and in commerce goes under the name of ricotti, wadding, neri, Galettame, Basinetto, etc.

4. Cocoons imperfect from various causes, such as being punctured by the worms, becoming spotted by pupa breaking, etc. These are known as cocons, perces, piques, tarmate, rugginose, etc. It forms a valuable material for floss silk spinning. The best grades contain 75 to 85 per cent. pure silk, and the average is about 65 per cent.

5. Double cocoons, which, in spite of the difficulty in reeling, were formerly used for special purposes. Now such cocoons are converted into waste which is known as Strussa.

6. Waste obtained in reeling the cocoons, known as Frisonnets.

7. A great variety of wild silks, which, for the most part, cannot be reeled, and are, therefore, first converted into waste. A large quantity of wild silk, even though it can be reeled, is torn up for waste.

8. Waste made by reeling, spooling, and other processes of working silk.

Silk shoddy resembles wool shoddy in origin, consisting of recovered fibres from manufactured silk goods. It nearly always contains isolated fibres of both wool and cotton, and frequently mixtures of different kinds of silk. There may also occur boiled-off, soupled, and raw silk, and mixtures of organzine and spun silk. Different colors are also usually present. The fibres, as a rule, are quite

The double silk fibre as it exists in the cocoon is known as the *bave*, and the single filaments are called *brins*.

The size of the single silk filament as it comes from the cocoon averages $2\frac{1}{4}$ deniers.* The following table gives the approximate size of filaments of mulberry silk from different countries:

Country.	Weight in 500 Meters	
	in Deniers	in Milligr.
Spain.	3.0	163
France.	2.6	138
Italy.	2.4	128
Syria.	2.4	128
Caucasus.	2.3	125
Brousse.	2.2	117
Japan.	2.1	113
China.	2.0	108
Bengal.	1.2	64

2. Wild Silks.—Besides the *Bombyx mori*, or mulberry silkworm, there are other associated varieties of caterpillars which also produce silk in sufficient quantity to be of considerable commercial importance. Due to the fact that such silkworms are not capable of being domesticated and artificially cultivated like the mulberry worms, the silk obtained from them is called wild silk. Of this latter there are several commercial varieties, of which the most important are here given.

short, being about a centimeter in length. Due to these components, silk shoddy is comparatively easy to recognize under the microscope.

* The fineness or size of the silk thread is expressed by a number known as titre (in French) or titolo (in Italian); this gives the number of units of certain weight (denier) a skein of certain length will weigh. Several different standards are in use at the present time, among which are the following:

	Weight in Milligrams.	Length in Meters.
Denier (legale).....	0.05	450
Denier milano.	0.051	476
Denier torino.	0.0534	476
Old denier Lyonese.	0.0531	476
New denier Lyonese.	0.0531	500
Denier international	0.05	500

The titre is usually expressed in the form of a fraction, representing limits of variation, as all skeins are not of absolutely the same size. A silk marked $18/20$, for instance, would mean that it varied from 18 to 20 deniers.

Antheræa yama-mai, a native of Japan, is a green-colored caterpillar which feeds on oak-leaves. Its cocoon is large and of a bright greenish color. The silk bears a close resemblance to that of the *Bombyx mori*, but is not as readily dyed and bleached as the latter.

Antheræa pernyi is a native of China; besides growing wild, it has been domesticated to some extent. This worm also feeds on oak-leaves, but is of a yellow color. Its cocoon is quite large, averaging over 4 cm. in length, and is of a yellowish to a brown color.

Antheræa assama is a native of India; it gives a large cocoon over 45 mm. in length.

Antheræa mylitta is another Indian variety, and furnishes the so-called *tussah* silk, though this term has also been applied in a general manner to all varieties of wild silk. The worms feed on the leaves of the castor-oil plant, and give very large cocoons, reaching 50 mm. in length and 30 mm. in diameter. The color varies from a grey to a deep brown.

Another variety of silkworm which is to be found both in Asia and America is the *Attacus ricini*; it gives a very white and good quality silk, the production and value of which is increasing every year. A species of this class, known as *Attacus atlas*, is perhaps the largest moth known; it spins open cocoons and gives the so-called Fagara, or Ailanthus, silk.

Wild silks are much more difficult to unwind from the cocoons than that of the mulberry silkworm. The silk is also much darker in color; it also has less strength and elasticity, and is much more difficult to dye and bleach.

Tussah (or tussur) silk (as well as other wild silks) is chiefly employed for making pile-fabrics, such as velvet, plush, and imitation sealskin.

3. The Microscopical and Physical Properties of Silk.—Under the microscope raw silk exhibits an appearance which readily distinguishes it from the textile fibres. It is seen as a smooth structureless filament, very regular in diameter and very transparent. The two brins in the bave of raw silk give beautiful colors with polarized light when examined microscopically. The sericin

coating, however, appears to have no such action. The latter, being hard and brittle, on bending develops transverse cracks which are very apparent under the microscope.

The fibre of *Bombyx mori* is only rarely striated longitudinally, and when such striations do appear they always run parallel to the axis of the fibre. When treated with dilute chromic acid very fine striations are caused to appear. Wild silks often show fibres which are twisted on their axes, and the layer of gum is usually more or less granular. *Antheræa mylitta* shows rather frequent oblique striations, and does not exhibit much play of color with polarized light. This latter characteristic is also true of *Antheræa yama-mai*. The other silks give colors with polarized light very nicely. Silk fibres are colored a deep red with alloxanthin; fuchsin also gives a red color. On treatment with sugar and sulphuric acid, silk is first colored a rose-red and then dissolves; hydrochloric acid gives a violet color and then dissolves the fibre. Iodin colors the fibres yellow to reddish brown.

Carded silk, which has been worked up from imperfect cocoons, etc., can usually be recognized under the microscope by the irregular and torn appearance of its external layer of gum.

The inner layers of the cocoon consist of a yellow parchment-like skin, and when examined under the microscope exhibit a matrix of sericin, in which numerous double fibres are imbedded, usually very much fattened in cross-section (Fig. 25, *a*). These

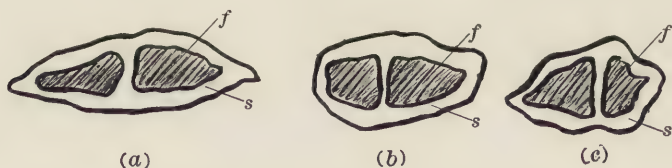


FIG. 25.—Cross-sections of Silk Fibre.

a, from inner part of cocoon; *b*, from middle layers of cocoon; *c*, from outer part of cocoon; *f*, fibre of fibroin; *s*, layer of sericin.

inner layers, of course, are not capable of being reeled with the rest of the cocoon, and are used for waste silk. The cross-sections of the fibres from the middle portion of the cocoon, con-

stituting the reeled silk, are much more rounded in form and surrounded with a thinner layer of sericin (see Fig. 25*b*). The fibres of the outer part of the cocoon, also utilized for waste silk, exhibit a rather irregular cross-section (see Fig. 25*c*).

When raw silk is examined under the microscope it will be seen that the appearance is by no means regular, owing to the broken and torn surface of sericin which surrounds the fibre (see

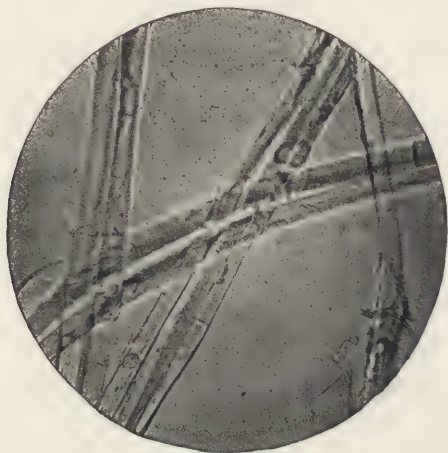


FIG. 26.—Fibres of Raw Silk ($\times 500$).
Showing the double filament and the irregular coating of silk-glue.

Fig. 26). Frequently, the two filaments of fibroin are distinctly separated from one another for considerable distances, the intervening space being filled in with sericin. Occasionally, the layer of sericin is seen to be entirely absent, having been removed by breaking or rubbing off. The sericin layer also shows frequent transverse fissures, which are merely cracks caused by the breaking of the sericin in the bending or twisting of the fibre. Creases and folds in the sericin, as well as irregular lumps, are also of frequent occurrence. All of these markings are in no wise structural, and only occur in the sericin layer. At times the fibroin fibre exhibits structural changes in places, such as discontinuities; but these only occur in defective and unhealthy silk, and give rise to weak places. These are caused by the fibroin not being secreted by the gland with sufficient rapidity.

The microscopic appearance of the wild silks is very different from that of the *Bombyx mori*. The fibres are very broad and thick, and in cross-section are very flat, and often triangular in outline. Longitudinally, they show very distinct striations, and peculiar flattened markings, usually running obliquely across the fibre, and in which the striations become more or less obliterated.

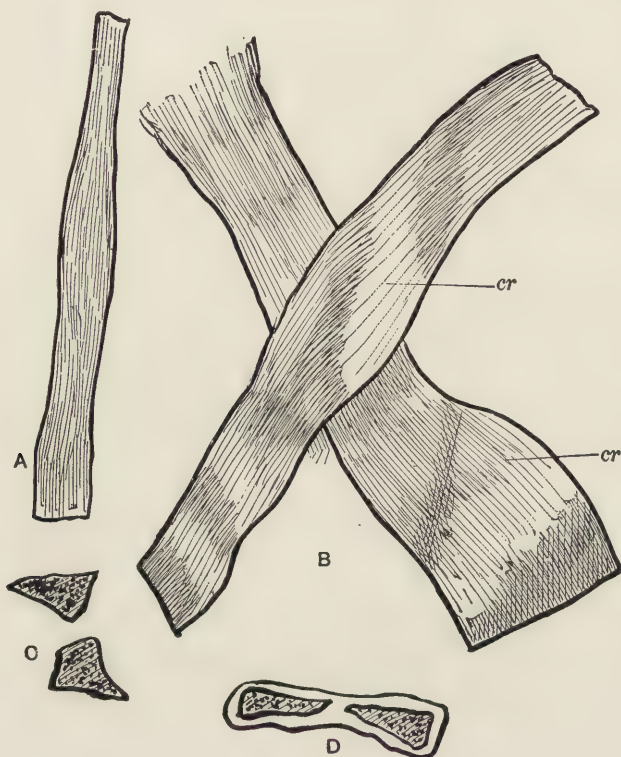


FIG. 27.—Wild Silks.

A, view of narrow side; *B*, view of broad side; *C*, cross-sections; *D*, cross-section of double fibre; *cr*, cross-marks on fibre.

These cross-markings are caused by the overlapping of one fibre on another before the substance of the fibre had completely hardened; in consequence of which, these places are more or less flattened out (see Fig. 27). The striated appearance of wild silk is evidence that structurally the fibre is composed of minute fila-

ments; in fact, the latter may readily be isolated by maceration in cold chromic acid. According to Höhnel, these structural elements are only 0.3 to 1.5 μ in diameter; they run parallel to each other through the fibre, and are rather more dense at the



FIG. 28.—Tussah Silk ($\times 340$). (Höhnel.)

A, view of narrow side; *B*, view of broad side; *C*, flat surface of single fibre showing two thin cross-marks at 1 and 2; *f*, air canals; *g*, fibrillæ; *D*, cross-section; *i*, inner layers; *r*, denser marginal layers.

outer portion of the fibre than in the inner part (see Fig. 28). Besides the fine striations on the fibres of wild silk caused by their structural filaments, there are also to be noticed a number of irregularly occurring coarser striations. These latter appear to be due to air-canals, or spaces between the filaments of the fibre (see Fig. 29).

Höhnel is of the opinion that there is really no difference in kind between the structure of wild silk and that of cultivated silk; that is to say, the fibroin fibre of the latter is also composed of structural filaments, only they fuse into one another in a more homogeneous manner on emerging from the fibroin glands, thus rendering it more difficult to recognize them superficially.

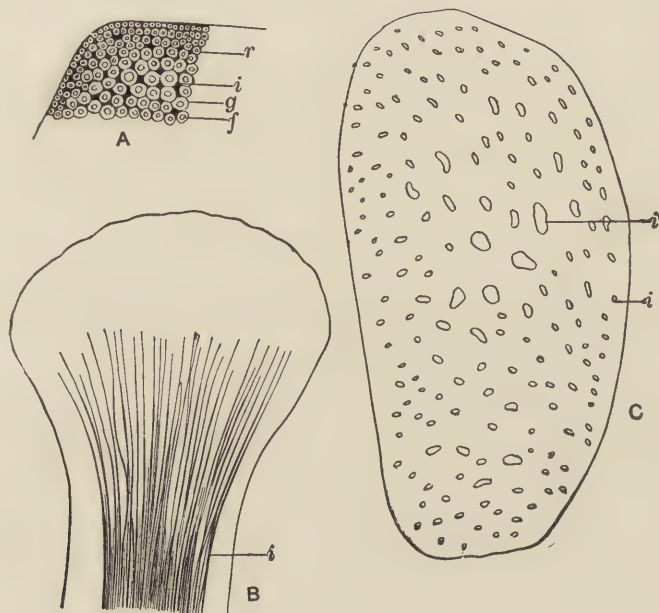


FIG. 29.—Cross-section of Wild Silk. (Höhnel.)

A, diagrammatic drawing of section; *i*, air-space; *g*, ground matrix; *f*, fibrillæ; *r*, marginal layer; *B*, end of fibre of tussah silk swollen in sulphuric acid; *C*, cross-section of fibre of tussah silk swollen in sulphuric acid.

This view is upheld somewhat by the fact that a slight striated appearance may be noticed when the silk fibre is macerated in chromic acid solution. This apparent structure of the silk fibre, however, may also be due to another cause. If a plastic glutinous mass (such as melted glue, for instance) be pulled out into the form of a thread and allowed to harden, it will be found to exhibit the same striated structure as the silk fibre; and this structure will be more apparent if the thread is pulled out and hardened more rapidly. The liquid fibroin in the glands of

the worm is a plastic glutinous mass analogous to melted glue, and is pulled out into the form of a thread by the action of the worm in winding its cocoon; hence it would be natural to expect a striated structure similar to that observed in the thread of glue. Thus, it is possible to account satisfactorily for the structure of the silk fibre in a perfectly natural manner, without having

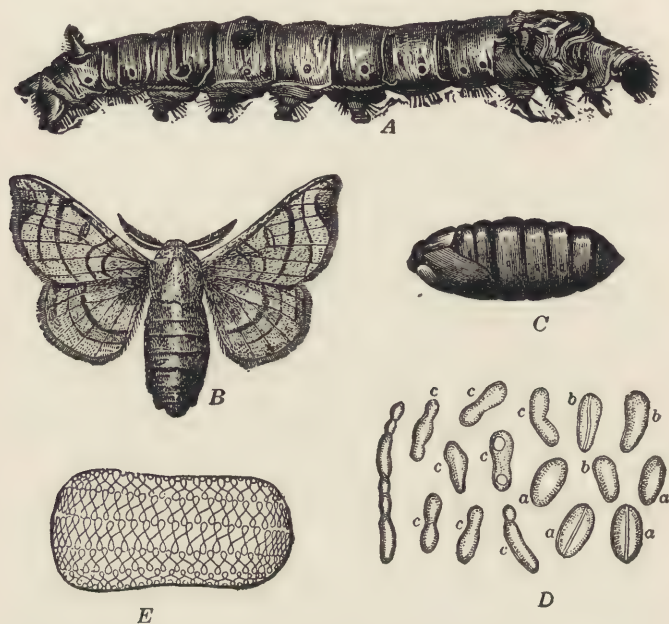


FIG. 29a.—Showing Different Stages in Growth of Silkworm.
A, silkworm in fifth period, full size; *B*, moth or butterfly; *C*, chrysalis or pupa;
D, eggs of moth; *E*, diagram showing cocoon and method of winding.

recourse to a very doubtful organic process in the formation of the fibre, such as is supposed to be the case by Höhnel.

Raw silk is quite hygroscopic, and under favorable circumstances will absorb as much as 30 per cent. of its weight of moisture, and still appear dry. It is therefore customary to determine the amount of moisture in each lot at the time of sale. This is called *conditioning*, and is usually carried out in official laboratories. The amount of moisture which is legally permitted is 11 per cent.

Being a bad conductor of electricity, silk is readily electrified by friction, which circumstance at times renders it difficult to handle in the manufacturing processes. The trouble can be overcome to a great extent by keeping the atmosphere moist.

The most striking physical property of silk, perhaps, is its high lustre. The lustre only appears after the silk has been scoured and the silk-gum removed. The lustre of silk is affected more or less by the various operations of dyeing and mordanting, and especially when the silk is heavily weighted. After dyeing,

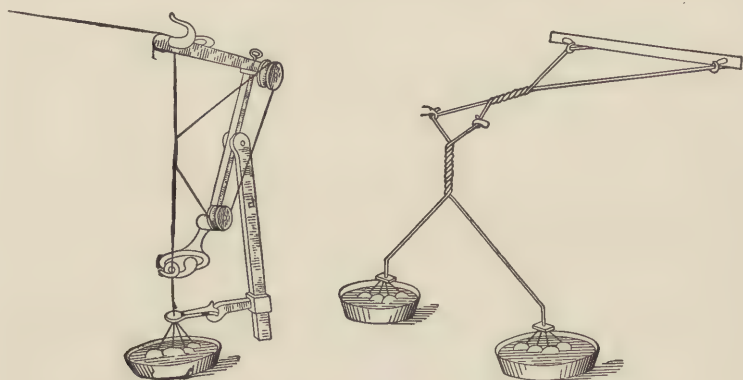


FIG. 29b.—Showing Methods of Reeling the Silk Fibre from the Cocoon.

especially in the skein form, silk usually undergoes what is termed a lustring operation, which consists generally in stretching the hanks strongly by twisting, and simultaneously steaming under pressure for a few minutes. This process seems to bring back to the dyed silk its lustre to a considerable extent. The lustre is also considerably affected by the method of dyeing and the chemicals employed in the dye-bath; it has been found that the addition of boiled-off liquor (the soap solution of sericin obtained in the degumming of raw silk) to the dye-bath has the result of preserving the lustre of the dyed silk better than anything else, and in consequence, boiled-off liquor is nearly always employed as the assistant in dyeing in preference to Glauber's salt or common salt.

Silk is also distinguished by its great strength. It is said that its tensile strength is almost equal to that of an iron wire of equal

diameter. The silk fibre is also very elastic, stretching 15 to 20 per cent. of its original length in the dry state before breaking. Degummed or boiled-off silk is much lower in strength and elasticity than raw silk, the removal of the silk-gum apparently causing a decrease of 30 per cent. in the tensile strength and 45 per cent. in the elasticity. The weighting of silk also causes a decrease in its strength and elasticity.

The following table gives the diameter, elasticity, and tensile strength of the cocoon-thread of the chief varieties of silks (Wardle, *Jour. Soc. Arts*, xxxiii. 671):

Name of Silk.	Country.	Diameter, Ins.		Elasticity, Ins. in 1 Ft.		Tensile Strength, Drams.		Size of Cocoon, Ins.
		Outer Fibres.	Inner Fibres.	Outer Fibres.	Inner Fibres.	Outer Fibres.	Inner Fibres.	
Bombyx mori.	China	.00052	.00071	1.3	1.9	1.6	2.6	1.1×0.5
Bombyx mori.	Italy	.00053	.00068	1.2	1.9	1.9	2.6	1.2×0.6
Bombyx mori.	Japan	.00057	.00069	1.2	1.4	2.0	3.1	1.1×0.6
Bombyx fortunatus	Bengal	.00045	.00051	1.8	2.3	1.6	2.8	1.2×0.5
Bombyx textor.	India	.00042	.00047	1.5	1.9	1.4	2.6	1.2×1.5
Antheræa mylitta. .	India	.00161	.00172	1.9	2.7	6.6	7.8	1.5×0.8
Attacus ricini.	India	.00085	.00093	1.7	2.0	1.5	3.0	1.5×0.8
Attacus cynthia. . .	India	.00083	.00097	2.6	2.9	2.4	3.5	1.8×0.8
Antheræa assama. .	India	.00128	.00125	2.4	2.9	2.8	4.8	1.8×1.0
Actius selene.	India	.00100	.00109	2.0	2.8	2.4	4.0	3.0×1.2
Attacus atlas.	India	.00102	.00111	1.9	2.8	2.1	4.1	3.5×0.8
Antheræa yama-mai.	Japan	.00088	.00096	2.0	4.0	6.8	7.5	1.5×0.8
Cricula trifenestrata	India	.....	.00120	.....	.....	.....	.....	2.0×0.8
Antheræa pernyi. . .	China	.00118	.00138	2.0	2.7	3.2	5.8	1.6×0.8

The density of silk in the raw state is 1.30 to 1.37, while boiled-off silk has a density of 1.25.

Another property of silk which is peculiar to this fibre, ordinarily, is what is termed its *scroop*; this refers to the crackling sound emitted when the fibre is squeezed or pressed. To this property is due the well-known rustle of silken fabrics. The scroop of silk does not appear to be an inherent property of the fibre itself, but is acquired when the silk is worked in a bath of dilute acid and dried without washing. A satisfactory explanation to account for the scroop has not yet been given; it is probably due to the acid hardening the surface of the fibre.

Mercerized cotton can also be given a similar scroop by such a treatment with dilute acetic acid. Wool, under certain conditions of treatment, can also be given this silk-like scroop, as, for instance, when it is treated with chloride of lime solutions or with strong caustic alkalies.

4. Silk-reeling.—The silk fibre as it appears in trade for use in the manufacture of textiles is obtained by unreeling the cocoon. After the cocoons have been spun by the silkworms they are heated in an oven for several hours at a temperature of 60° to 70° C. for the purpose of killing the pupa or chrysalis contained within, before the latter shall have developed sufficiently to begin cutting its way through the envelope and thus destroy the continuity of the cocoon-thread. Another method of operation is to steam the cocoons; this requires only a few minutes to kill the pupa, and is said to be preferable to the oven-heating, as it causes less damage to the fibre, and at the same time considerably softens the silk-glue, thus rendering the subsequent process more easy. After the killing of the worms is accomplished the cocoons are sorted into several grades, according to size, color, extent of damage, etc., after which they are ready for reeling. This is entirely a mechanical process requiring much skill. The cocoons are soaked in warm water until the silk-glue is softened; the operator seizes the loose ends of several fibres together on a small brush and passes them through the porcelain guides of a reel, where they are twisted together to form threads of sufficient size for weaving. Two threads are formed simultaneously on each reel, and are made to cross and rub against each other to remove twists in the fibre (see Fig. 29*b*), and also to rub the softened silk-glue coverings together in order that the fibres may become firmly cemented and form a uniform thread. The product so obtained is termed *raw silk* or *grège*; *floss silk*, which is used for making *spun silk*, is the term applied to the waste resulting from short and tangled fibres from the exterior of the cocoon, and from those cocoons which have been broken by the moth in escaping. Raw silk is classified into two grades: (a) *Organzine* silk, which is made from the best selected cocoons, and is chiefly used for warps on account of its greater strength;

and (b) *Tram* silk, which is made from the poorer quality cocoons, and is mostly employed for filling. Floss or waste silk cannot be reeled, so the cocoon-threads are scoured in a solution of soda and soap, and afterwards combed and carded in special machines. The better quality and longer fibre is worked up into what is known as *florette* silk, while the shorter fibres are carded and spun into *bourette* silk. Floss silk is also known as *chappe* or *échappe* silk.

CHAPTER VII.

CHEMICAL NATURE AND PROPERTIES OF SILK.

1. **Chemical Constitution.**—The glands of the silkworm appear to secrete two transparent liquids. The one, *fibroin*, constituting from one-half to two-thirds of the entire secretion, forms the interior and larger portion of the silk fibre; the other, *sericin*, also called *silk-glue*, forms the outer coating of the fibre. The latter substance is yellowish in color, and is readily soluble in boiling water, hot soap, and alkaline solutions. As soon as discharged into the air the fluids from the spinneret solidify, and coming into contact with each other at the moment of discharge, are firmly cemented together by the sericin.

The amount of sericin present in raw silk is about 25 per cent., and this causes the fibre to feel harsh and to be stiff and coarse. Before being manufactured into textiles the raw silk is subjected to several processes with a view to making it soft and glossy. The first treatment is called *discharging*, *stripping*, or *ungumming*, and has for its purpose the removal of the silk-glue. It is really a scouring operation, the silk being worked in a soap solution* at a temperature of 95° C. In this process the silk loses from 20 to 30 per cent. in weight, but becomes soft and glossy. After several successive scourings the soap solution becomes heavily charged with sericin, and is subsequently utilized in the dye-bath as an assistant under the name of *boiled-off liquor*.

* Alkaline carbonates are not to be recommended for silk-scouring, as they are liable to injure the fibre, especially at elevated temperatures. Soft water should also be employed, as lime makes the fibre brittle.

According to Mulder, samples of yellow Italian silk analyzed as follows:

	Per Cent.
Silk fibre.	53.35
Matter soluble in water.	28.86
“ “ “ alcohol.	1.48
“ “ “ ether.	0.01
“ “ “ acetic acid.	16.30

He gives the chemical composition of the silk fibre as follows:

	Per Cent.
Fibroin.	53.37
Gelatin.	20.66
Albumin.	24.43
Wax.	1.39
Coloring-matter.	0.05
Resinous and fatty matter.	0.10

According to Richardson, mulberry silk has the following composition:

	Per Cent.
Water.	12.50
Fats.	0.14
Resins.	0.56
Sericin.	22.58
Fibroin.	63.10
Mineral matter.	1.12

Analysis of samples of mulberry silk is given by H. Silbermann as follows:

	White.		Yellow.	
	Cocoons.	Raw.	Cocoons.	Raw.
Fibroin.	73.59	76.20	70.02	72.35
Ash of fibroin.	0.09	0.09	0.16	0.16
Sericin.	22.28	22.01	24.29	23.13
Wax and fat.	3.02	1.36	3.46	2.75
Salts.	1.60	0.30	1.92	1.60

The amount of ash in boiled-off silk will vary somewhat according to the origin of the silk, but will average about 0.50 per cent. In raw silk the average amount of ash will be about 1 per cent. In yama-mai silk the ash may reach as high as 8 per cent.

Fibroin is a proteoid somewhat analogous to that contained in wool, and, like the latter, it is no doubt an amido-acid.* Mulder gives the analysis of fibroin as follows:

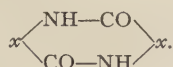
	Per Cent.
Carbon.	48.80
Hydrogen.	6.23
Oxygen.	25.00
Nitrogen.	19.00

Vignon analyzed samples of highly purified silk,† and gives the following figures:

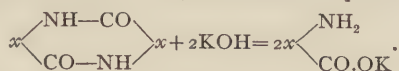
	Per Cent.
Carbon.	48.3
Hydrogen.	6.5
Nitrogen.	19.2
Oxygen.	26.0

The proportion of fibroin in raw silk has been variously stated by different observers, and appears to differ with the method employed for its determination. The figure given by Mulder (see above) of 53.35 per cent. was obtained by boiling the raw silk with acetic acid. By the action of a 5 per cent. solution of cold caustic soda, Städeler obtained 42 to 50 per cent. of fibroin. Cramer obtained 66 per cent. by heating raw silk in water at 133° C. under pressure. Francézon reports 75 per cent. of fibroin by twice boiling the silk in a solution of soap and then treating with acetic acid. Vignon, by carefully purifying the fibroin by suitable treatment, obtained 75 per cent.

* Richardson suggests the following structural formula for fibroin, allowing x to represent a hydrocarbon residue:



The decomposition of fibroin by saponification with potash would then be



† Vignon prepared pure fibroin in the following manner: A 10-gram skein of raw white silk is boiled for thirty minutes in a solution of 15 grams of neutral soap in 1500 c.c. water; rinse in hot, then in tepid water; squeeze and repeat the treatment in a fresh soap-bath; rinse with water, then with dilute hydrochloric acid, again with water; finally, wash twice with 90 per cent. alcohol. The fibroin thus obtained leaves only 0.01 per cent. of ash on ignition. (*Compt. rend.*, cxv. 17, 613).

Unlike keratin, the proteoid of wool, fibroin contains no sulphur, and is much more constant in its composition. The empirical formula for fibroin as given by Mulder is $C_{15}N_{23}N_5O_6$. Mills and Takamine give the formula as $C_{24}H_{38}N_8O_8$, while Schützenberger gives $C_{71}H_{107}N_{24}O_{25}$. Cramer arrives at the same formula as Mulder, while Richardson (*Jour. Soc. Chem. Ind.*, xii. 426) gives $C_{60}H_{94}N_{18}O_{25}$. Vignon's formula for specially purified fibroin is $C_{22}H_{47}N_{10}O_{12}$.*

The presence of the amido-group in fibroin has been shown, as in the case of wool (see page 37), by diazotizing the fibre with an acid solution of sodium nitrite, then washing and treating with solutions of various developers, such as phenol, resorcinol, alpha- and beta-naphthols, etc., whereby the fibre becomes dyed in different colors.

From its action towards alcoholic potash Richardson concludes† that silk-fibroin is more probably an amido-anhydride rather than an amido-acid. When boiled for a long period with dilute sulphuric acid fibroin is dissolved to a yellowish brown liquid, leaving as a residue only a small amount of what is apparently a fatty acid. From this decomposition product Weyl (*Ber.*, xxi. 1529) succeeded in isolating 5.2 per cent. of tyrosin, 7.5 per cent. of glycocin, and 15 per cent. of a crystalline compound which was apparently alpha-alanin. Towards Millon's and Adamkiewitz's reagents fibroin gives the usual reaction of proteids, and it also gives the biuret test.† According to Richardson,

* Silbermann found that fibroin heated with a solution of barium hydrate under pressure was decomposed with the formation of oxalic, carbonic, and acetic acids, together with an amido body approximating the formula $C_{68}H_{141}N_{21}O_{48}$. The latter compound is said to undergo further decomposition with the formation of tyrosin, glycocin, alanin, amido-butyric acid, and an amido-acid of the acrylic series.

† Millon's reagent consists of a solution of mercurous nitrate containing nitrous acid in solution. It is prepared by treating 1 c.c. of mercury with 10 c.c. of nitric acid (sp. gr. 1.4), heating gently until complete solution is effected, then diluting the solution with twice its volume of cold water. When a solution of a proteid is treated with this reagent a white precipitate is first formed which turns brick-red on boiling; a solid proteid becomes red when boiled with the reagent. Adamkiewitz's test is to dissolve the proteid in glacial acetic acid, and then add concentrated sulphuric acid to the solution, when a fine violet color will be produced, and the liquid will exhibit a faint fluorescence. The biuret test is to add a few

silk-fibroin will absorb 30 per cent. of iodine when treated with Hübl's reagent. Attempts have been made to acetylate fibroin, but without success.

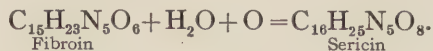
Fibroin is insoluble in ammonia and solutions of the alkaline carbonates; neither is it dissolved by a 1 per cent. solution of caustic soda, but stronger solutions affect it, especially if hot. From its solution in caustic soda fibroin may be reprecipitated by dilution with water. Fibroin is also soluble in hot glacial acetic acid, and in strong hydrochloric, sulphuric, nitric, and phosphoric acids. Alkaline solutions of the hydroxides of such metals as nickel, zinc, and copper also dissolve fibroin.

If silk-fibroin is dissolved in cold concentrated hydrochloric acid, and the solution be allowed to stand sixteen hours at the ordinary temperature with three times its volume of hydrochloric acid (sp. gr. 1.19), it will no longer be precipitated by the addition of alcohol. The fibroin appears to have suffered hydrolysis, being converted into a body similar to peptone. This substance may be separated out by steaming the above solution under diminished pressure. If its aqueous solution be neutralized with ammonia and some trypsin ferment be added, tyrosine will begin to crystallize out in a few hours.

Sericin, according to the analysis of Richardson, has the following composition:

	Per Cent.
Carbon.....	48.80
Hydrogen.....	6.23
Oxygen.....	25.97
Nitrogen.....	19.00

and its formula is given as $C_{16}H_{25}N_5O_8$. It is considered as probably being an alteration of fibroin; strong hydrochloric acid is said to convert the latter into sericin; the conversion is supposed to take place by assimilation of water and oxygen:



drops of a dilute solution of copper sulphate to the solution of proteid; on then adding an excess of caustic soda solution the precipitate which at first formed will be dissolved with the production of a fine violet coloration.

Sericin may be obtained in a pure condition by first boiling a sample of raw silk in water for several hours, after which the sericin is precipitated by lead acetate.* On treatment with dilute sulphuric acid sericin yields a small quantity of leucin and tyrosin, but no trace of glycoll, the principal product formed being a crystalline body called *serin*, which appears to have the formula $C_3H_7NO_3$, and from its chemical reactions is evidently analogous to glycerin, probably being amido-glyceric acid.

Sericin is soluble in hot water, hot soap solutions, and dilute caustic alkalis. The aqueous solution is precipitated by alcohol, tannin, basic lead acetate, stannous chloride, bromine, and iodine, and by potassium ferrocyanide in the presence of acetic acid.† Mulder gives the formula of $C_{15}H_{25}N_5O_8$ to sericin, and the following composition:

	Per Cent.
Carbon.	42.60
Hydrogen.	5.90
Oxygen.	35.00
Nitrogen.	16.50

According to Bolley, the composition of sericin is:

	Per Cent.
Carbon.	44.32
Hydrogen.	6.18
Oxygen.	31.20
Nitrogen.	18.30

* Pure sericin may also be prepared by precipitating crude sericin solution with 1 per cent. acetic acid, washing the separated sericin by repeated decantation with water, then treating with cold and afterwards with boiling alcohol, and finally extracting with ether. Pure sericin contains:

C	45.00 per cent.
H	6.32 " "
N	17.14 " "
O	31.54 " "

It is easily soluble in water, in concentrated hydrochloric acid, and in potassium carbonate; sodium carbonate only causes a swelling.

† By treatment with formaldehyde it is claimed that sericin is rendered insoluble in both hot water and soap solutions; consequently raw silk may be treated with this reagent for use in certain applications where it may be desired to retain as far as possible the coating of silk-glue.

Vignon,* by observing the action of solutions of sericin and fibroin on polarized light, found that both of these constituents of silk were lævogyrates, and their rotatory powers were about equal, approximating to 40° . This is in keeping with observations made on other albuminoids.

According to Dubois,† the yellow coloring-matter of silk is similar to carotin. He obtained five different bodies from the natural coloring-matter of silk, as follows: (1) a golden-yellow coloring-matter, soluble in potassium carbonate and precipitated by acetic acid; (2) crystals which appear yellowish red by transmitted light and brown by reflected light; (3) a lemon-colored amorphous body, the alcoholic solution of which on evaporation gave granular masses; (4) yellow octahedral crystals resembling sulphur; (5) a dark bluish green pigment in minute quantities and probably crystalline.

2. Chemical Reactions.—In its general chemical behavior silk is quite similar to wool. It will stand a higher temperature, however, than the latter fibre, without receiving injury; it can be heated, for instance, to 110° C. without danger of decomposition; at 170° C., however, it is rapidly disintegrated. On burning it liberates an empyreumatic odor which is not as disagreeable as that obtained from burning wool. Silk readily absorbs dilute acids from solutions, and in so doing increases in lustre and acquires the scroop of which mention has already been made. Unlike wool, it has a strong affinity for tannic acid, which fact is utilized for both weighting and mordanting the fibre. Silk also absorbs sugar to a considerable degree, and this substance may be employed as a weighting material for light-colored silks on this account. Towards the ordinary metallic salts used as mordants silk exhibits quite an affinity; in fact, to such an extent can it absorb and fix certain metallic salts that silk material is frequently heavily mordanted with such salts for the purpose of unscrupulously increasing its weight.

Solutions of sodium chloride appear to have a peculiar action on the silk-fibre, especially in the presence of weighting materials.

* *Compt. rend.*, CXIII. 802.

† *Ibid.*, CXI. 482.

According to the researches of Sisley, solutions of common salt acting on weighted silk in the presence of air and moisture cause a complete destruction of the fibre in twelve months if charged with but 0.5 per cent. of salt; 1 per cent. of salt causes a very pronounced tendering of the fibre in two months, while 2 to 5 per cent. of salt causes a distinct tendering in seven days. The action of the salt is shared in a lesser degree by the chlorides of potassium, ammonium, magnesium, calcium, barium, aluminium, and zinc, and is probably due to chemical dissociation. This fact may account for the stains sometimes found in skeins of silk which also show a tendering of the fibre. These stains have frequently been noticed, and thorough investigation has failed to satisfactorily account for them. The salt may get into the fibre through the perspiration of the workmen handling the goods, or through a variety of other causes.

Silk is not as sensitive to dilute alkalies as wool, though the lustre of the fibre is somewhat diminished.* When treated with strong hot alkalies the silk fibre dissolves. Ammonia and soaps have no effect on silk beyond dissolving off the silk-glue or sericin; though on long-continued boiling in soap, the fibroin is also attacked. Concentrated sulphuric † and hydrochloric acids dissolve silk; nitric acid colors silk yellow, ‡ as in the case with wool,

* It is said that when mixed with glucose or glycerin caustic soda does not dissolve the silk fibre to any extent, but only removes the gum.

† Though silk is soluble in concentrated acids if their action is continued for any length of time, it appears that if silk be treated with concentrated sulphuric acid for only a few minutes, then rinsed and neutralized, the fibre will contract from 30 to 50 per cent. in length without otherwise suffering serious injury beyond a considerable loss in lustre. This action of concentrated acids on silk has been utilized for the *crêping* of silk fabrics, the acid being allowed to act only on certain parts of the material. It appears that tussah silk is not affected by the acid to the same degree as ordinary silk, and hence *crêping* may be accomplished by mixing tussah with ordinary silk, and treating the entire fabric with concentrated acid.

‡ The action of nitric acid on silk is rather a peculiar one. When treated for one minute with nitric acid of sp. gr. 1.33 at a temperature of 45° C., the silk acquires a yellow color which cannot be washed out and is also fast to light. Pure nitric acid free from nitrous compounds, however, does not give this color. On treating the yellow nitro-silk with an alkali the color is considerably deepened. With strong sulphuric acid nitro-silk swells up and gives a gelatinous mass resembling egg albumin.

probably due to the formation of xanthroproteic acid. This color can be removed by treatment with a boiling solution of stannous chloride. A concentrated solution of basic zinc chloride readily dissolves the silk fibre.* An acid solution of zinc chloride also acts in the same manner. Solutions of copper oxide or nickel oxide in ammonia also act as solvents towards silk. The latter solution can be employed for separating silk from cotton, the silk being readily and completely soluble in a boiling solution of ammoniacal nickel oxide, whereas cotton loses less than 1 per cent. of its weight. A boiling solution of basic zinc chloride (1:1) will dissolve silk in one minute, while cotton under the same treatment loses only 0.5 per cent., and wool only 1.5 to 2 per cent.† Chlorine destroys silk, as do other oxidizing agents, unless employed in very dilute solutions and with great care.

Hydrofluosilicic acid and hydrofluoric acid in the cold and in 5 per cent. solutions do not appear to exert any injurious action on the silk-fibre; these acids, however, remove all inorganic weighting materials, and their use has been suggested for the restoring of excessively weighted silks to their normal condition, so that they may be less harsh and brittle.

Towards coloring-matters in general, silk exhibits a greater capacity of absorption than perhaps any other fibre. It also absorbs dyestuffs at much lower temperatures than does wool.

3. **Tussah Silk** presents a number of differences, both physically and chemically, from ordinary silk. It has a brown color and is considerably stiffer and coarser. It is less reactive, in general, towards chemical reagents, and consequently presents

* On diluting this solution with water a flocculent precipitate is obtained which is soluble in ammonia, and the latter solution has been employed for coating vegetable fibres with silk for the production of certain so-called "artificial silks."

† Silk is also soluble in Schweitzer's reagent (cupro-ammonium hydrate), and in an alkaline solution of copper sulphate and glycerin. The latter is used to separate silk from wool and cotton; and the following solution is recommended: 16 grams copper sulphate, 10 grams glycerin, and 150 c.c. of water. After dissolving, add a solution of caustic soda, until the precipitate which at first forms is just redissolved.

more difficulty in bleaching and dyeing. Tussah silk requires a much more severe treatment for ungumming than cultivated silk, and the boiled-off liquor so obtained is of no value in dyeing.

According to analyses of Bastow and Appleyard* raw tussah silk gives the following results:

	Per Cent
Soluble in hot water.	21.33
Dissolved by alcohol (fatty acid)	0.91
Dissolved by ether.	0.08
Total loss on boiling off with 1 per cent. solution of soap.	26.49
Mineral matter.	5.34

These same observers consider that the fibroin of tussah silk differs chemically from that of ordinary silk, as it is much less readily acted on by solvents. In order to obtain pure tussah fibroin the silk should be boiled repeatedly with a 1 per cent. solution of soap, washed with water, extracted with hydrochloric acid; and after again washing with water and drying, extracted successively with alcohol and ether. Tussah fibroin purified in this manner shows the following composition:

	Per Cent.
Carbon.	47.18
Hydrogen.	6.30
Nitrogen.	16.85
Oxygen.	29.67

These figures are exclusive of 0.226 per cent. of ash. Appleyard gives the following analysis of the ash from raw tussah silk:

	Per Cent.
Soda, Na_2O	12.45
Potash, K_2O	31.68
Alumina, Al_2O_3	1.46
Lime, CaO	13.32
Magnesia, MgO	2.56
Phosphoric acid, P_2O_5	6.90
Carbonic acid, CO_2	11.14
Silica, SiO_2	9.79
Hydrochloric acid, Cl	2.89
Sulphuric acid, SO_3	8.16

* *Jour. Soc. Dyers' and Col.*, IV. 88.

The presence of sulphates in this ash is somewhat remarkable, as this constituent does not occur in ordinary silk. The occurrence of alumina is also remarkable, as this element is seldom a constituent of animal tissues. As the amount of ash of purified fibroin of both common silk and tussah silk is very much lower than that of the raw silks, it is to be considered probable that most of the mineral matter found is derived from adhering impurities, and is not a true constituent of the silk itself.

Tussah silk is scarcely affected by an alkaline solution of copper hydrate in glycerin, whereas ordinary silk is readily soluble in this reagent.*

The following table exhibits the principal differences between true silk and tussah silk:†

Reagent.	True Silk.	Tussah Silk.
Hot caustic soda (10%)	Dissolves in 12 minutes	Requires 50 minutes for solution
Cold hydrochloric acid (sp. gr. 1.16)	Dissolves very rapidly	Only partially dissolves in 48 hours
Cold conc. nitric acid	Dissolves in 5 minutes	Dissolves in 10 minutes
Neutral solution of zinc chloride (sp. gr. 1.725)	Dissolves very rapidly	Dissolves but slowly
Strong chromic acid solution in water	Dissolves very rapidly	Dissolves very slowly

While the fibre of true silk presents the appearance of a structureless thread, and rarely exhibits signs of distinct striation, tussah (and other "wild" silks) is made up of bundles of delicate fibrillæ, varying in diameter from 0.0003 to 0.0015 mm., so that the fibre as a whole presents a striated appearance. Also the cross-section ‡ of tussah silk is considerably larger than that of true silk, and is more flattened; it also exhibits numerous fine air-tubes. The following table exhibits the difference in the microscopic appearance of various kinds of raw silk; the diameter is expressed in μ = thousandths of a millimeter:§

* Filsinger, *Chem. Zeit.*, XX. 324.

† Bastow and Appleyard, *Jour. Soc. Dyers' and Col.*, IV. 89.

‡ Filsinger, *vide supra*.

§ Höhnelt, *Jour. Soc. Chem. Ind.*, II. 172.

Variety of Silk.	Diameter.	Appearance.	
		Broad Side.	Narrow Side.
True silk, <i>Bombyx mori</i>	20 to 25	White or yellowish; shiny	White or yellowish; Shiny
Senegal silk, <i>B. jaidherbi</i>	30 to 35	Shining yellowish or brownish white, or pale yellow, gray, brown, and occasionally bluish white	Gray, brown, or black, with occasionally lighter shades
Ailanthus silk, <i>B. cynthia</i>	40 to 50	Shining yellowish white, with yellow, brown, or brownish-gray spots	Dirty gray or brown to black, with green, yellow, red, violet, or blue spots
Yama-mai silk, <i>Antheræa yama-mai</i>	40 to 50	Bluish white with dark blue, blue and black shades	Glaring and fine colors, with dark or black shades
Tussah silk, <i>Actius selene</i>	50 to 55	Irregular in thickness. Thickest parts with gray and blue spots; thinner parts bluish white, yellow, or orange-red	Dark gray, with pink or light green spots
Tussah silk, <i>Antheræa mylitta</i>	60 to 65	Similar to above, but spots orange-red, red, or brown	Similar to above

CHAPTER VIII.

THE VEGETABLE FIBRES.

1. THE basis of all vegetable fibres is to be found in cellulose, a compound belonging to a class of naturally occurring substances known as carbohydrates. The fibres may be either *seed-hairs*, such as the different varieties of cotton, cotton-silk, etc.; or *bast fibres*, which include those obtained from the cambium layer of the dicotyledonous plants, such as flax, hemp, jute, ramie, etc.; or *vascular fibres*, which include those obtained chiefly from the leaf-tissues of the monocotyledonous plants, such as phormium, agave, aloe, etc.*

Anatomically considered, the plant fibres may be divided into six different classes (Höhnelt):

(1) Single-cell plant-hairs, such as cotton, vegetable silk, and vegetable down.

(2) Fibres consisting of several cells, such as pulu fibre, elephant-grass, and cotton-grass.

(3) Bast fibres, such as flax, hemp, jute, ramie, etc.

(4) Dicotyledonous bast fibres, such as linden-bast, Cuba bast, etc.

(5) Monocotyledonous vascular fibres, such as sisal hemp, aloe-hemp, pineapple fibre, cocoanut fibre, etc.

* There is a peculiar instance in which the entire plant is used as the fibre; this is sea-grass or sea-wrack (*Zostera marina*). However, it can scarcely be considered as a textile fibre, as it is almost altogether employed for stuffing and packing.

(6) Monocotyledonous sclerenchymous fibres, such as Manila hemp, New Zealand flax, etc.

There is considerable difference to be observed between the anatomical structure of seed-hairs and that of bast fibres. Seed-hairs are known botanically as plumose fibres, and consist of a unicellular fibre or trichome, exhibiting only a single solid apex, the other end being attached to the seed. Externally they appear to be covered with a thin skin or cuticle which differs essentially from the remaining cellulose in that it is not dissolved by treatment with sulphuric acid. The cell-walls vary considerably in their thickness, and are structureless and porous. Through the centre of the fibre runs a hollow canal, called the lumen, the chief content of which appears to be air. Usually the dried fibre is flattened into the form of a band, and the lumen then becomes almost nothing. Bast fibres, on the other hand, consist of completely enclosed tubes, each end being pointed. Each individual fibre is multicellular, the cells being long and usually polygonal in cross-section. The cell-walls are usually rather thick, and the cross-section instead of being flat and narrow is broad and more or less rounded. The inner wall is frequently covered with a thin layer of dried protoplasm. One of the most characteristic appearances of the bast fibres is the occurrence of dislocations or joints throughout the length of the fibre. These dislocations also show the property of becoming more deeply colored than the rest of the fibre when treated with a solution of chlor-iodide of zinc. These knots or joints generally show thicker overlying transverse fissures, between which lie small short discs arranged on edge. The joints disappear altogether in the monocotyledonous fibres; they are also lacking on many true bast fibres, such as jute, linden-bast, etc., but occur in hemp, flax, ramie, etc.

Bast fibres are the long, tough cells found in the bark and stem of various plants. The cell-walls of these fibres are usually partially changed from pure cellulose into lignin and are thickened. There is usually a considerable amount of foreign matter also contained in the cell-wall, and often this becomes sufficiently characteristic to serve as a means of identifying the various

fibres by the application of chemical reagents. Unlike seed-hairs, the individual cells of bast fibres are not of sufficient length for use in spinning, but as they are held together with considerable firmness to form bundles of great length, they are utilized in this form.

Wiesner gives the following table showing the length of the raw fibre and the dimensions of the cells composing them:

Fibre	Length of Raw Fibre, cm	Length of Cells, mm.	Breadth of Cells.		
			Min. μ .	Max. μ .	Aver. μ
Tillandsia fibre.	2-22	0.2-0.5	6	15	
Esparto grass.	10-40	1.5-1.9	9	15	
<i>Cordia latifolia</i>	50-90	0.1-1.6	14.7	16.8	15
<i>Phormium tenax</i>	80-110	2.5-5.6	8	29	13
<i>Abelmochus tetraphyllos</i>	60-70	0.1-1.6	8	20	16
<i>Bauhinia racemosa</i>	50-150	1.5-4.0	8	20	
Jute (<i>Corchorus capsularis</i>).	150-300	0.8-4.1	10	21	16
<i>Thespesia lampas</i>	100-180	0.9-4.7	12	21	16
<i>Urena sinuata</i>	100-120	1.1-3.2	9	24	15
<i>Sida retusa</i>	80-100	0.8-2.3	15	25	
<i>Calotropis gigantea</i> (bast).	20-30	0.7-3.0	18	25	
<i>Aloe perfoliata</i>	40-50	1.3-3.7	15	24	
Flax (<i>Linum usitatissimum</i>).	20-140	2.0-4.0	12	25	16
Hemp (<i>Cannabis sativa</i>).	100-300	0.8-4.1	16	32	20
Jute (<i>Corchorus olitorius</i>).	150-300	0.8-4.1	16	32	20
<i>Hibiscus cannabinus</i>	40-90	4.0-12.0	20	41	
Sunn (<i>Crotalaria juncea</i>).	20-50	0.5-6.9	20	42	
<i>Bromelia karatas</i>	100-110	1.4-6.7	27	42	
China grass (<i>Böhmmeria nivea</i>).	22.0	40	80	50	
Ramie (<i>Böhmmeria tenacissima</i>).	8.0	16	12.6		
Cotton (<i>Gossypium barbadense</i>).	4.05	40.5	19.2	27.9	25.2
do. (<i>G. conglomeratum</i>).	3.51	35.1	17	27.1	25.5
do. (<i>G. herbaceum</i>).	1.82	18.2	11.9	22	18.9
do. (<i>G. acuminatum</i>).	2.84	28.4	20.1	29.9	29.4
do. (<i>G. arboreum</i>).	2.50	25.0	20	37.8	29.9
Cotton wool (<i>Bombax heptaphyllum</i>).	2-3	20-30	19	29	
Vegetable silk (<i>Calotropis gigantea</i>). ..	2-3	20-30	12	42	38
do. (<i>Asclepias</i>).		10-30	20	44	
do. (<i>Marsdenia</i>).		10-25	19	33	
do. (<i>Strophanthus</i>).		10-50	49	92	
do. (<i>Beaumontia</i>).		30-45	33	50	
Linden-bast.		1.1-2.6			15
<i>Sterculia villosa</i>		1.5-3.5	17	25	20
<i>Holoptelia integrifolia</i>		0.9-2.1	9	14	12
<i>Kydia calycina</i>		1-2	17	24	
<i>Lasiosiphon speciosus</i>		0.4-5.1	8	29	
<i>Sponia wightii</i>		4			21
<i>Pandanus odoratissimus</i>		1.0-4.2			20
Pita fibre.		1.0-2.2	16	21	17
Coir fibre.		0.4-0.9	12	20	16

Vétillard gives a somewhat similar table as follows:

Name.	Length (in mm.).			Breadth (in μ).			Ratio of Breadth to Length.
	Min.	Max.	Mean.	Min.	Max.	Mean.	
Linen.	4	66	25	15	37	20	1200
Hemp (<i>Cannabis sativa</i>).	5	55	20	16	50	22	1000
Hop fibre (<i>Humulus lupulus</i>).	4	19	10	12	26	16	620
Nettle fibre (<i>Urtica dioica</i>).	4	57	27	20	70	50	550
Ramie (<i>Urtica nivea</i>).	60	250	120	80	50	2400	
Fibre of paper mulberry.	25	10	30	350			
Sunn hemp (<i>Crotalaria juncea</i>).	4	12	8	25	50	30	260
Broom-grass (<i>Sarothamnus vulgaris</i>).	2	9	5	10	25	15	330
Feather-grass (<i>Spartium junceum</i>).	5	16	10	20	500		
<i>Melilotus alba</i>	5	18	10	20	36	30	330
Cotton.	10	40					
Gambo hemp (<i>Hibiscus cannabinus</i>)	2	6	5	14	33	21	240
Linden-bast (<i>Tilia europæa</i>).	1.2	5	2	14	20	16	125
Jute (<i>Corchorus capsularis</i>).	1.5	5	2	20	25	22.5	90
<i>Lagetta linlearia</i>	3	6	5	10	20	500	
<i>Salix alba</i>	3	2	17	30	22	90	
Esparto.	0.5	3.5	1.5	7	18	12	125
<i>Lygæum spartum</i>	1.3	4.5	2.5	12	20	15	160
Pineapple fibre.	3	9	5	4	8	6	830
<i>Bromelia karatas</i>	2.5	10	5	20	32	24	210
<i>Bromelia pinguin</i>	0.8	2.5	2	8	16	13	150
<i>Phormium tenax</i> (New Zealand flax).	5	15	9	10	20	16	550
<i>Yucca</i> fibre.	0.5	6	4	10	20	15	170
<i>Sanseveria</i> fibre.	1.5	6	3	15	26	20	150
<i>Agave americana</i>	1.5	4	2.5	20	32	24	100
<i>Musa textilis</i> (Manila hemp).	3	12	6	16	32	24	250
<i>Musa paradisaica</i>	5	20	40	28	180		
<i>Phœnix dactylifera</i>	2	6	3	16	24	20	150
<i>Corypha umbraculifera</i>	1.5	5	3	16	28	24	120
<i>Elaïs guineensis</i>	1.5	3.5	2.5	10	13	11	230
<i>Raphia taetigera</i>	1.5	3	2.5	12	20	16	160
<i>Mauritia flexuosa</i>	1	3	1.5	10	16	12	130
Coir fibre (<i>Cocas uncijera</i>).	0.4	1	0.7	12	24	20	35

2. **Classification.**—Perhaps the most systematic and complete enumeration of the various vegetable fibres, together with a classification of their technical uses, is that given by Dodge in his "*Report on the Useful Plant Fibres of the World*," from which the following abstract is taken:

STRUCTURAL CLASSIFICATION.

A. FIBROVASCULAR STRUCTURE.

1. *Bast fibres.*—Derived from the inner fibrous bark of dicotyledonous plants or exogens, or outside growers. They are

composed of bast-cells, the ends of which overlap each other, so as to form in mass a filament. They occupy the phloem portion of the fibrovascular bundles, and their utility in nature is to give strength and flexibility to the tissue.

2. *Woody fibres.*

(a) The stems and twigs of exogenous plants, simply stripped of their bark and used entire, or separated into withes for weaving or plaiting into basketry.

(b) The entire or subdivided roots of exogenous plants, to be employed for the same purpose, or as tie material, or as very coarse thread for stitching or binding.

(c) The wood of exogenous trees easily divisible into layers or splints for the same purposes, or more finely divided into thread-like shavings for packing material.

(d) The wood of certain soft species of exogenous trees, after grinding and converting by chemical means into wood-pulp, which is simple cellulose, and similar woods more carefully prepared for the manufacture of artificial silk.

3. *Structural fibres.*

(a) Derived from the structural system of the stalks, leaf-stems, and leaves, or other parts of monocotyledonous plants, or inside growers, occurring as isolated fibrovascular bundles, and surrounded by a pithy, spongy, corky, or often a soft, succulent, cellular mass covered with a thick epidermis. They give to the plant rigidity and toughness, thus enabling it to resist injury from the elements, and they also serve as water-vessels.

(b) The whole stems, or roots, or leaves, or split and shredded leaves of monocotyledonous plants.

(c) The fibrous portion of the leaves or fruits of certain exogenous plants when deprived of their epidermis and soft cellular tissue.

B. SIMPLE CELLULAR STRUCTURE.

4. *Surface fibres.*

(a) The down or hairs surrounding the seeds, or seed envelopes, of exogenous plants, which are usually contained in a husk, pod, or capsule.

(b) Hair-like growths, or tomentum, found on the surfaces of stems and leaves, or on the leaf-buds of both divisions of plants.

(c) The fibrous material produced in the form of epidermal strips from the leaves of certain endogenous species, as the palms.

5. *Pseudo-fibres, or false fibrous material.*

(a) Certain of the mosses, as the species of the *sphagnum*, for packing material.

(b) Certain leaves and marine weeds, the dried substance of which forms a more delicate packing material.

(c) Seaweeds wrought into lines and cordage.

(d) Fungous growths, or the mycelium of certain fungi that may be applied to economic uses, for which some of the true fibres are employed.

The bast fibres are clearly defined, and all such fibres when simply stripped are similar in form as to outward appearance, differing chiefly in color, fineness, and strength. An example of a fine bast fibre is the ribbons or filaments of hemp. The woody fibres are only fibrous in the broad sense, as their cellulose is broken down and all extraneous matter removed by chemical means, as for the manufacture of paper-pulp or of artificial silk. The structural fibres are found in many forms differing widely from each other, and the surface fibres are still more varied in form.

ECONOMIC CLASSIFICATION.

A. SPINNING FIBRES.

1. *Fabric fibres.*

(a) Fibres of the first rank for spinning and weaving into fine and coarse textures for wearing apparel, domestic use, or house furnishing and decoration, and for awnings, sails, etc. (The commercial forms are cotton, flax, ramie, hemp, pineapple, and New Zealand flax.)

(b) Fibres of the second rank, used for burlap or gunny, cotton bagging, woven mattings, floor coverings, and other coarse uses. (Commercial examples are coir and jute.)

2. *Netting fibres.*

(a) Lace fibres, which are cotton, flax, ramie, agave, etc.

(b) Coarse netting fibres, for all forms of nets, and for hammocks. (Commercial forms: Cotton, flax, ramie, New Zealand flax, agave, etc.)

3. *Cordage fibres.*

(a) Fine spun threads and yarns other than for weaving; cords, lines, and twines. (All of the commercial fabric fibres, sunn, Mauritius, and bowstring hems, New Zealand flax, coir, Manila, sisal hems; the fish-lines made from seaweeds.)

(b) Ropes and cables. (Chiefly common hemp, sisal and Manila hems, when produced commercially.)

B. TIE MATERIAL (*rough twisted*).

Very coarse material, such as stripped palm-leaves, the peeled bark of trees, and other coarse growths used without preparation.

C. NATURAL TEXTURES.

1. *Tree-basts, with tough interlacing fibres.*

(a) Substitutes for cloth, prepared by simple stripping and pounding.

(b) Lace-barks, used for cravats, frills, ruffles, etc., and for whips and thongs.

2. *The ribbon or layer basts*, extracted in thin, smooth-surfaced, flexible strips or sheets. (Cuba bast used as millinery material, cigarette wrappers, etc.)

3. *Interlacing structural fibre or sheaths.*

(a) Pertaining to leaves and leaf-stems of palms, such as the fibrous sheaths found at the bases of the leaf-stalks of the cocoanut.

(b) Pertaining to flower-buds. The natural caps or hats derived from several species of palms.

D. BRUSH FIBRES.

1. *Brushes manufactured from prepared fibre.*

(a) For soft brushes. (Substitutes for animal bristles, such as Tampico.)

(b) For hard brushes. (Examples: Palmetto fibre, palmyra, kittul, etc.)

2. *Brooms and whisks.*

(a) Grass-like fibres. (Examples: Broom-root, broom-corn, etc.)

(b) Bass fibres. (Monkey bass, etc.)

3. *Very coarse brushes and brooms.*

Material used in street cleaning. Usually twigs and splints.

E. PLAITING AND ROUGH-WEAVING FIBRES.

1. *Used in hats, sandals, etc.*

(a) Straw-plaits. From wheat, rye, barley, and rice-straw. (Tuscan and Japanese braids.)

(b) Plaits from split leaves, chiefly palms and allied forms of vegetation. (Panama hats.)

(c) Plaits from various materials. (Bast and thin woods used in millinery trimmings.)

2. *Mats and mattings; also thatch materials.*

(a) Commercial mattings from Eastern countries.

(b) Sleeping-mats, screens, etc.

(c) Thatch-roofs, made from tree-basts, palm-leaves, grasses, etc.

3. *Basketry.*

(a) Manufactures from woody fibre.

(b) From whole or split leaves or stems.

4. *Miscellaneous manufactures.*

Willow-ware in various forms; chair-bottoms, etc., from splints or rushes.

F. VARIOUS FORMS OF FILLING.

1. *Stuffing or Upholstery.*

(a) Wadding, batting, etc., usually commercially prepared lint-cotton.

(b) Feather substitutes for filling cushions, etc.; cotton, seed-hairs, tomentum from surfaces of leaves, other soft fibrous material.

(c) Mattress and furniture filling. The tow or waste of

prepared fibre; unprepared bast, straw, and grasses; Spanish moss, etc.

2. *Caulking.*

(a) Filling the seams in vessels, etc.; oakum from various fibres.

(b) Filling the seams in casks, etc.; leaves of reeds and giant grasses.

3. *Stiffening.*

In the manufacture of "staff" for building purposes, and as substitutes for cow-hair in plaster. New Zealand flax; palmetto fibre.

4. *Packing.*

(a) In bulkheads, etc. Coir, cellulose of corn-pith. In machinery, as in valves of steam-engines; various soft fibres.

(b) For protection in transportation; various fibres and soft grasses; marine weeds; excelsior.

G. PAPER MATERIAL.

1. *Textile papers.*

(a) The spinning fibres in the raw state; the secondary qualities or waste from spinning mills, which may be used for paper stock, including tow, jute-butts, Manila rope, etc.

(b) Cotton or flax fibres that has already been spun and woven, but which, as rags, finds use as a paper material.

2. *Bast papers.*

This includes Japanese papers from soft basts, such as the paper mulberry.

3. *Palm papers.*

From the fibrous material of palms and similar plants. Palmetto and Yucca papers.

4. *Bamboo and grass papers.*

This includes all paper material from gramineous plants, including the bamboos, esparto, etc.

5. *Wood-pulp, or cellulose.*

The wood of spruce, poplar, and similar "paper-pulp" woods prepared by various chemical and mechanical processes.

3. Physical Structure and Properties.—Seed-hairs, or plumose fibres, are divided into three morphological classes:

(1) Those consisting of single cells, one end of which is closed and tapers to a point, the other end being broken off abruptly where it is torn from the seed to which it was fastened during growth. This class includes the most important plumose fibres, such as cotton and the vegetable silks.

(2) Those consisting of a series of cells joined together to form a continuous fibre; this class includes the tomentum or epidermal hair obtained from certain ferns, and are practically valueless as textile materials, though used for upholstery and such purposes.

(3) Those consisting of several series of cells, represented by the fibres of the so-called *cotton-grass* and *elephant-grass*.

The cell-wall of the plumose fibres in some cases is relatively thin, while in others it is comparatively thick. It is generally without apparent structure, though sometimes it is seen to contain pores, and occasionally a mesh-like interlacing of filaments is observable, especially at the base of the fibre. The inner surface of the cell-wall is usually coated with a cuticle of dried protoplasm, which is evidently similar in constitution to the outer cuticle, as it also remains undissolved when the fibre is dissolved in either concentrated sulphuric acid or an ammoniacal solution of copper oxide. The general term of the bast fibre includes really two distinct forms; if the fibre occurs in the bast itself it should be designated as true *bast fibres*, such as linen, hemp, and jute. When, however the fibres occur not in the bast, but in single bundles in the leaf structure of the plant, they should be designated as *sclerenchymous fibres*. In true bast fibres there are seldom to be noticed distinct pores, whereas the sclerenchymous fibres are abundantly supplied with them. On the other hand, however, the true bast fibres frequently show peculiar dislocations or joints caused by an unequal cell-pressure in the growing plant; these are entirely absent in the sclerenchymous fibres. The ends of all bast fibres are usually quite characteristic and exhibit a wide diversity of forms; at times they are sharp-pointed and again blunt; some possess

but a single point, while others are split or forked; sometimes the cell-wall is thicker than in the rest of the fibre, and sometimes it is thinner. When the cells occur in bundles they are frequently separated from one another by a so-called *median layer*, which forms a sort of matrix in which the separate filaments are imbedded. This layer usually differs in its chemical composition from the cell-wall proper, and gives different color reactions with various reagents, as it generally consists of lignified tissue. In many cases the cell-walls appear to have a distinct structure, being composed of concentric layers which in cross-section exhibit a stratified appearance.

Although cellulose forms the chief constituent of all vegetable fibres, it varies much in its purity and associated products in its occurrence in the various fibres. Seed-hairs like cotton consist almost entirely of cellulose in a rather pure state, but the bast and vascular fibres always contain more or less alteration products of cellulose, chief among which is ligno-cellulose or lignin; in fact, jute is almost entirely composed of this latter substance. Seed-hairs consist of one single cell to the individual fibre and have very little foreign or incrusting material present. The other fibres are made up of an aggregation of cells bound together in a compact form, and in the cell interstices there is always present more or less gummy and resinous matter, oils, mineral matter, and lignified tissue. All vegetable fibres appear to contain more or less pigment matter, usually of a slight yellowish or brownish color. In ordinary cotton and ramie this coloring-matter occurs in only a very small amount and the natural fibre is quite white in appearance. There are some varieties of cotton, however, which are distinctly brown in color. Flax, jute, hemp, etc., contain a considerable amount of pigment and are of a brownish color more or less pronounced.

Besides cellulose and lignin, there is also present, especially in seed-hairs, a cutose membrane (cork-tissue) in the form of an external cuticle. Cutose is very insoluble in concentrated sulphuric acid, but is partially soluble in boiling potash. It doubtless originates from the plant-wax which is imbedded in the cell. Albuminous matter also occurs in the fibre elements, mostly as a

dried tissue which fills the lumen of the fibre more or less completely. It also occurs as a thin film which coats the inner wall of the cell, and remains undissolved when the fibre is treated with concentrated sulphuric acid. This membrane exhibits all the reactions of albumin. Silicic acid sometimes is present in vegetable fibres, but only in the walls of the stigmata and in epidermal cells. On ignition the silicious matter is left in almost the original form of the fibre. The silicious skeleton is insoluble in hydrochloric acid, whereas the rest of the ash is readily dissolved by this reagent. Crystals of calcium oxalate occasionally occur in some fibres; they are insoluble in acetic but dissolve in hydrochloric acid. On ignition of the fibres these crystals are converted into calcium carbonate without much change of form, and then are soluble in even very dilute acids.

All plant-cell membranes are doubly refractive towards light, and this is especially true of thick-walled cells which are parallel to the fibre proper. If such a fibre is examined in the dark field of a micro-polariscope it shows a beautiful arrangement of bright prismatic colors.

In *color* the vegetable fibres vary considerably in the raw state; some, like cotton, ramie, and the vegetable silks, are almost pure white. Others, like linen, possess a grayish brown color; while others yet, like jute and hemp, have a decided brown color. These colors, however, are due to incrusting impurities, as the cellulose fibres, purified and freed from all such foreign matters, are always white.

In *lustre* the vegetable fibres are usually below those of animal origin, and especially silk, though they differ much in this respect. Cotton probably has the least lustre of any, as its external surface is by no means smooth and even, but presents a wrinkled and creased appearance, hence scatters the rays of light reflected therefrom. The other plumose fibres, as the various vegetable silks, have a very smooth surface, and consequently exhibit considerable lustre. Linen, jute, ramie, and the bast fibres in general, when decorticated to their fine filaments, and properly freed from all incrusting matter, possess a rather high degree of lustre; for though they have more or less roughened places and

irregularities on their external surface, the majority of such surface is smooth and regular.

The more closely the fibre approximates to pure cellulose, the greater becomes its *flexibility* and *elasticity*; and the more it is lignified the less these qualities become. That is to say, the highly lignified fibres are stiff and brittle, and but little adapted to the spinning of fine yarns.

The *hygroscopic* moisture contained in vegetable fibres is considerably lower than that present in either wool or silk. While the latter fibres under normal atmospheric conditions will average as much as 12 to 18 per cent. of moisture, cotton and linen will have only from 6 to 8 per cent. The following table (after Wiesner) gives the amount of moisture in various vegetable fibres in the ordinary air-dry condition, and also the greatest amount they will absorb hygroscopically:

HYGROSCOPIC MOISTURE IN VEGETABLE FIBRES.

Fibre.	Air-dry Condition.	Maximum Amount Hygroscopic Water.
Cotton.	6.66	20.99
Flax (Belgian).	5.70	13.90
Jute.	6.00	23.30
China grass.	6.52	18.15
Manila hemp.	12.50	40.00
Sunn hemp.	5.31	10.87
<i>Hibiscus cannabinus</i>	7.38	14.61
<i>Abelmoschus tetraphyllos</i>	6.80	13.00
Esparto.	6.95	13.32
<i>Urena sinuata</i>	7.02	15.20
Piassave.	9.26	16.98
<i>Sida retusa</i>	7.49	17.11
<i>Aloe perfoliata</i>	6.95	18.03
<i>Bromelia karatas</i>	6.82	18.19
<i>Thespesia lampas</i>	10.83	18.19
<i>Cordia latifolia</i>	8.93	18.22
<i>Bauhinia racemosa</i>	7.84	19.12
Tillandsia fibre.	9.00	20.50
Pita.	12.30	30.00
<i>Calotropis gigantea</i> (bast).	5.67	13.13

CHAPTER IX.

COTTON.

1. Origin and Growth.—The use of cotton as a textile fibre dates back to antiquity, mention of it being found in the writings of Herodotus (445 B.C.). It was used in India, Egypt, and China. The first European country to make cotton goods appears to have been Spain.

The cotton fibre consists of the seed-hairs of several species of the genus *Gossypium*, belonging to the natural order of *Malvaceæ*.

The cotton plant is a shrub which reaches the height of 4 to 6 ft. It is more or less indigenous to nearly all sub-tropical countries, though it appears to be best capable of cultivation in warm, humid climates where the soil is sandy, and in the neighborhood of the sea, lakes, or large rivers. It appears to thrive most readily in North and South America, India, and Egypt; it has also been cultivated in Australia, but not as yet with any great degree of success; inferior qualities have been grown along the coasts of Africa; that grown in Europe (Italy and Spain) is practically negligible, as far as commercial considerations are concerned. In America, India, and Egypt the cotton plant is annual in its growth, but in hot tropical climates, and in South America, it becomes a perennial plant, and assumes more of a tree-like form. The leaf of the cotton plant has three-pointed lobes; the flower has five petals, yellow at the base, but becoming almost white at the edges. The fruit of the cotton plant forms the cotton boll, which contains the seeds with the attached fibres. The boll consists of from three to five segments, and on ripening

bursts open and discloses a mass of pearly white downy fibres (Fig. 30), in which are imbedded the brownish black to black-colored cottonseeds. The cotton boll should be picked as soon as possible after ripening; the seeds are then separated from the fibres by a process known as *ginning*. Besides the fibre itself, nearly all of the other products of the cotton are now utilized commercially. The seeds are of especial value, as they contain a

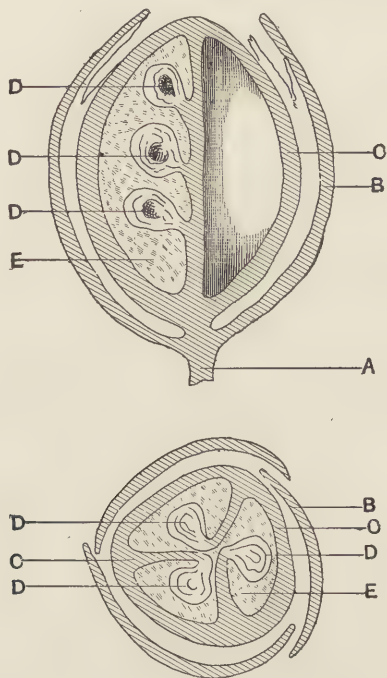


FIG. 30.—Sections of the Cotton Boll (Egyptian). (Witt.)
A, stem; B, calyx; C, capsule; D, seed; E, cotton fibre.

large quantity of oil, which is expressed and used for soap-making and many other purposes, while the residuum of meal and hulls is converted into cattle foods and fertilizer. The short fibres, or nep, left on the seed after the first ginning, are also recovered by a second process and used in the manufacture of lint and cotton-batting. The separation of seed particles from the fibre is not always perfect, and they frequently make their appearance in gray calico in the form of black specks or motes, and as these

contain small quantities of oil and tannin matters which are pressed out into the surrounding fibres, they cause specks and unevenness in dyeing and finishing. If they come in contact with solutions or materials containing iron compounds, a violet stain will be produced, the color of which, however, may not develop for some months.

Bowman (*loc. cit.*) gives an excellent description of the physiological development of the cotton fibre, from which the following is quoted: "In their earliest stages the young cotton

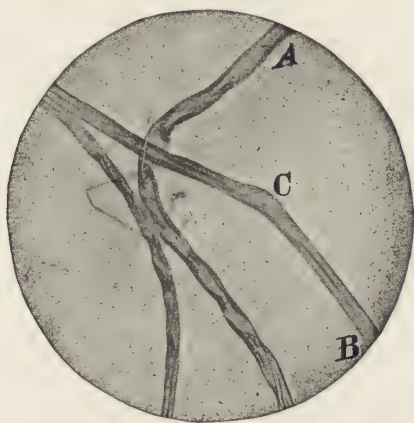


FIG. 31.—Typical Cotton Fibres.

A, normal fibre showing regular twists; *B*, straight fibre without twists; *C*, a knot or irregularity in growth of fibre.

fibres appear to have a circular section arising from the comparative thickness of the tube-walls; but as these walls gradually become thinner by the longitudinal growth of the hair and the pressure to which they are subjected by the contact of surrounding fibres enclosed within the pod, they gradually become flattened, and just before the pod bursts the outer walls of the cells have become so attenuated in the longest fibres as to be almost invisible even under high microscopic powers, and present the appearance of a thin, pellucid, transparent ribbon. With the bursting of the pod, however, a change occurs. The admission of air and sunlight causes a gradual unfolding of the hairy plexus, and the rapid consolidation of the liquid cell contents on the inner surface of the cell-wall gives them a greater thickness and

density, which is further increased by the gradual shrinking in of the walls themselves upon the cell contents. There is also a gradual rounding and thickening of the fibre, which increases by the deposition of matter on the inner wall of the cell. As this action is not perfectly uniform, arising from the unequal exposure of different parts of the fibres to light and air, it causes a twisting of the hairs, which is always a characteristic of cotton when viewed under the microscope, and the flat collapsed portions of the tube form so many reflecting surfaces, to which the

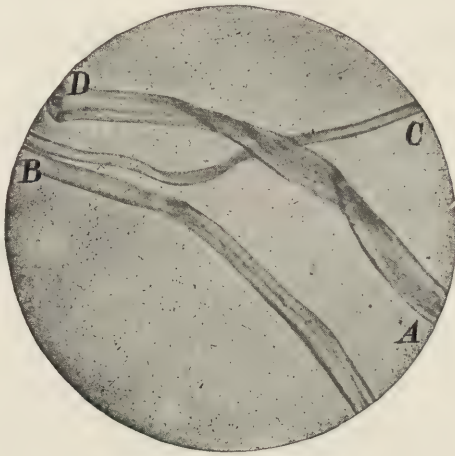


FIG. 32.—Typical Cotton Fibres.

A, broad, flat fibre near the base; *B*, thick rounded fibre; *C*, fibre near the pointed end; *D*, cut end of fibre.

brightness of the fibre when stretched tight in the fingers is no doubt due. Another change also occurs at this stage, a change which corresponds to the ripening of fruit. In the earliest period of their formation the growing cells are filled with juices which are more or less astringent in character. Under the influence of light and air these cell contents undergo a chemical change, in which the astringent principles are replaced by more or less saccharine or neutral juices, until in the perfectly ripe cotton fibre the cell-walls are composed of almost pure cellulose.

The cell-wall of the cotton is thin in comparison with that of the bast fibres, but in comparison with the other seed-hairs it is remarkably thick. This accounts for its much greater strength

over the latter. In completely developed fibres, the thickness of the cell-wall is from one-third to two-thirds of the total thickness of the fibre itself.

The quality of the cotton fibre depends not only on the species of the plant from which it is derived, but also on the manner of its cultivation. The conditions which exercise, perhaps, the greatest influence are : (a) the seed, (b) the soil, (c) the mode of cultivation, (d) the climatic conditions. The seed for sowing must be carefully and specially chosen for the purpose. A very dry soil produces harsh and brittle cotton, the fibres of which are very irregular in length; a moist and sandy soil produces a very desirable cotton of long and fine staple. The best soil is considered to be a light loam, while a damp clay is regarded as the worst. Soils situated in proximity to the sea, and therefore containing considerable saline matter, appear to furnish the most valuable varieties of cotton, and it is claimed that the saline constituents of the soil have considerable influence on the growth and development of the cotton fibre.

2. Varieties of Cotton.—The classification of the different species of cotton plant varies with different authorities; the most comprehensive, perhaps, is to classify the different varieties of the cotton plant as (1) the tree, (2) the shrub, and (3) the herbaceous species.* According to Parlatore all commercial

* The following list of species of the cotton-plant are more or less recognized by botanists:—

- G. album* Hamilton, a synonym of *G. herbaceum*; commercially known as upland cotton; has a white seed.
- G. arboreum* Linn., a tree-like plant; perennial; indigenous to India; produces but little fibre.
- G. barbadense* Linn., indigenous to America and outlying islands; gives the highly prized sea-island cotton.
- G. brasiliense* Macfad., a tropical species; belongs to the so-called "kidney-cottons"; the seeds adhere to one another in clusters.
- G. chinense* Fisch. & Otto, a synonym for *G. herbaceum*; a Chinese cotton.
- G. croceum* Hamilton, a synonym for *G. herbaceum*; possesses a yellow lint.
- G. eglandulosum* Cav., a synonym for *G. herbaceum*.
- G. elatum* Salisb., a synonym for *G. herbaceum*.
- G. frutescens* Lasteyr., a synonym for *G. barbadense*.
- G. fuscum* Roxb., a synonym for *G. barbadense*.
- G. glabrum* Lam., a synonym for *G. barbadense*.
- G. glandulosum* Stend., a synonym for *G. herbaceum*.

cotton is derived from seven species of the *Gossypium*, which he enumerates as follows:

(1) *G. barbadense*, which comprises the long-stapled and silky-fibred cottons known as *Barbadoes*, *Sea-island*, *Egyptian*, and *Peruvian*. The plant reaches a height of from 6 to 8 ft.,

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- G. herbaceum* Linn., usually considered of Asiatic origin; synonymous with *G. hirsutum*; ordinary upland cotton.
- G. hirsutum* Linn., of American origin; Georgia upland cotton.
- G. indicum* Lam., a synonym for *G. herbaceum*.
- G. jamaicense* Macfad., a synonym for *G. barbadense*; grows in Jamaica.
- G. javanicum* Blume, a synonym for *G. barbadense*; grows in Java.
- G. latifolium* Murr., a synonym for *G. herbaceum*.
- G. leonimum* Medic., a synonym for *G. herbaceum*.
- G. macedonicum* Murr., a synonym for *G. herbaceum*.
- G. maritimum* Tod., a synonym for *G. barbadense*.
- G. micranthum* Cav., a synonym for *G. herbaceum*.
- G. molle* Mauri, a synonym for *G. herbaceum*.
- G. nanking* Meyen, a synonym for *G. herbaceum*.
- G. neglectum* Tod., indigenous to India; similar to *G. arboreum*; extensively grown in India; gives the Dacca and China cottons.
- G. nigrum* Hamilton, a synonym for *G. barbadense*.
- G. obtusifolium* Roxb., a synonym for *G. herbaceum*.
- G. oligospermum* Macfad., a synonym for *G. barbadense*.
- G. paniculatum* Blanco, a synonym for *G. herbaceum*.
- G. perenne* Blanco, a synonym for *G. barbadense*.
- G. peruvianum* Cav., a synonym for *G. barbadense*.
- G. punctatum* Schum. & Thonn., a synonym for *G. barbadense*.
- G. racemosum* Poir, a synonym for *G. barbadense*.
- G. religiosum* Par., a synonym for *G. arboreum*; so-called because its use is mostly restricted to making turbans for Indian priests; also because it grows in the gardens of the temples; it has the cultural name of Nurma or Deo cotton. Also a variety of *G. barbadense*.
- G. roxburghianum* Tod., a variety of *G. neglectum*; corresponds to the Dacca cotton of India.
- G. siamense* Tenore, a synonym for *G. herbaceum*.
- G. sinense* Fisch., a synonym for *G. herbaceum*.
- G. stocksii* Masters, a synonym for *G. herbaceum*; claimed to be the original of all cultivated forms of this latter species.
- G. strictum* Medic., a synonym for *G. herbaceum*.
- G. tomentosum*, indigenous to the Sandwich Islands; the bark is used for making twine.
- G. tricuspidatum* Lam., a synonym for *G. herbaceum*.
- G. vitifolium* Lam., a synonym for *G. barbadense*.
- G. vitifolium* Roxb., a synonym for *G. herbaceum*.
- G. wightianum* Tod., a synonym for *G. herbaceum*; claimed by Todaro to be the primitive forms of the Indian cottons.

and has yellow blossoms. Owing to variations in the conditions of its cultivation, however, the present sea-island cotton has changed considerably from the original *barbadense*. This variety is employed for the spinning of fine yarns, such as are known in trade as "Bolton counts."

(2) *G. herbaceum*, including most of the cotton from India, southern Asia, China, and Italy. It is an annual plant growing from 5 to 6 ft. in height; unlike the *barbadense* variety, its seeds are generally covered with a soft undergrowth of fine down, which is an objectionable feature. The flower is yellow in color. This species is perhaps the hardiest of the cottons, and is cultivated over a wider range of latitude. It forms the source of nearly all the Indian cotton. It is used for the spinning of low-count yarns, also for the making of condenser yarns for the manufacture of flannelettes.

(3) *G. hirsutum*, including most of the cotton from the southern United States, also known as *upland* cotton. The plant is shrubby in appearance, seldom reaching more than 7 ft. in height; like the preceding variety, the seeds are also covered with a fine undergrowth of down.

(4) *G. arboreum*, including the cotton from Ceylon, Arabia, etc. As the name indicates, it is a tree-like plant, and grows from 12 to 18 ft. in height. The fibres are of a greenish color and very coarse; its flowers are of a reddish color.

(5) *G. peruvianum*, including the native Peruvian and Brazilian cottons. This differs from other varieties of cotton in that it is a perennial plant; the growth from the second and third years, however, only is utilized.

(6) *G. tahitense*, found chiefly in Tahiti and other Pacific islands.

(7) *G. sandwichense*, occurring principally in the Sandwich Islands.

This classification is claimed to include all the commercial varieties of cotton; it is probable, however, that the last two can be included under the *barbadense* and *hirsutum* varieties, as they possess the same characteristics as these fibres.

Other authorities on the botany of the cotton plant have rec-

ognized many more species than those above described. Agostino Todaro has described 52 varieties, while the Index Kewensis records 42 distinct species and refers to 88 others which it classifies as synonyms. Hamilton reduces the number of species to three, namely, the white-seeded, black-seeded, and yellow-linted, assigning to these species the botanical names *album*, *nigrum*, and *croceum*. The chief difficulty experienced in the botanical classification of the cotton plant is the fact that it hybridizes very readily and has a tendency to suffer alteration in variety with change in the conditions of its cultivation or variation in the character of the soil or climate.

Besides the varieties of cotton above enumerated, which are practically all which find any important commercial application, there is another plant which yields a fibre somewhat similar to cotton, and known as the silk-cotton plant. It belongs to the same natural order, *Malvaceæ*, as the ordinary cotton plant, but is of a different genus, being *Salmalia* instead of *Gossypium*. It grows principally on the African coast and in some parts of tropical Asia. The plant is rather a large tree, reaching from 70 to 80 ft. in height. The blossoms are red in color, and the seeds are covered with long silky fibres, which are not adapted, however, for spinning.

Although fibres from the different species of the cotton-plant all possess the same general physical appearance, nevertheless there are characteristic features in each worthy of careful observation.

Gossypium barbadense: *Sea-island*. — This constitutes the most valuable, perhaps, of all the different species. Its chief points of superiority are (*a*) its length, being more than half an inch longer than the average of other cottons; (*b*) its fineness of staple; (*c*) its strength; (*d*) its number of twists, which allow it to be spun to finer yarns; (*e*) its appearance, it being quite soft and silky. It is also characterized by a light-cream color. Sea-island cotton is mostly used for the production of fine yarns ranging from 120's to 300's; it is said that as fine as 2000's has been spun from it.* On account of its adaptability for mercer-

* The "count" of cotton yarn means the number of hanks of 840 yards each

izing it is also largely employed for this purpose, in which case much coarser yarns are often prepared from it. Owing to the wide cultivation of sea-island cotton at the present time, for its growth is no longer strictly confined to the islands of the sea, it is difficult to make a definite statement as to its length of staple, as this will vary considerably with the method and place of cultivation. The maximum length, however, may be taken as 2 ins., and the minimum as $1\frac{3}{4}$ ins., with a mean of $1\frac{5}{8}$ ins. *Florida sea-island* cotton is very similar in general characteristics to sea-island proper, possessing about the same mean length of staple, but being somewhat less in the maximum length. Both of these varieties of sea-island show a maximum diameter of 0.000714 in., a minimum of 0.000625 in., and a mean of 0.000635 in. *Fiji sea-island* is less regular in its properties than the two preceding varieties, and though its maximum length is somewhat greater than sea-island itself, yet the mean length is about the same, as is also the diameter. This cotton, however, has a very irregular staple and contains a large percentage of imperfect fibres, which causes the waste to be rather high. The number of twists in the fibre is also less and does not occur as regularly. *Gallini Egyptian* cotton is sea-island cotton grown in Egypt. It is somewhat inferior to the American varieties in general properties. It possesses a yellowish color which distinguishes it from the product of all other countries. The maximum length of the fibre is $1\frac{5}{8}$ ins., the minimum $1\frac{1}{4}$ ins., and the mean $1\frac{1}{2}$ ins. The fibres differ very little in their diameter, the average being 0.000675 in. *Peruvian sea-island* is somewhat coarser in structure than the sea-island proper, being more hairy in appearance; it has a

contained in 1 lb. The size 120's, for instance, means cotton yarn of such fineness that 120 hanks of 840 yards (= 100,800 yards) weigh 1 lb. The French method of numbering is based on the decimal system, and the count means the number of hanks each 1000 meters in length required to weigh 500 grams. In order to change from French to English count, multiply the former by 0.847, or $\frac{17}{20}$. The Belgian method of counting is to use the number of 840-yard hanks in 500 grams. The Austrian system is the number of hanks of 950 ells each contained in 500 grams. The English system is the one mostly used, being employed in England, America, India, Germany, Italy, and Switzerland, and even in parts of Austria.

slight golden tint. In staple it varies from $1\frac{3}{4}$ ins. in length to $1\frac{3}{8}$ ins., with a mean of $1\frac{1}{2}$ ins. *Tahiti sea-island* resembles the Fiji variety very closely; it has a creamy color. The length of staple varies from $1\frac{3}{4}$ to $1\frac{1}{4}$ ins., with a mean of $1\frac{1}{2}$ ins. It shows a considerable percentage of imperfect fibres due to a short undergrowth on the seed. Its average diameter is 0.000641 in.

Gossypium herbaceum.—*Smyrna* cotton is grown principally in Asiatic Turkey. It has a rather characteristic appearance under the microscope, being very even in its diameter but irregular in its twist, showing many fibres where the twist is almost entirely absent. In length the staple varies from $1\frac{1}{8}$ to $\frac{7}{8}$ ins., with a mean of 1 in.; the mean diameter is about 0.00077 in. *Brown Egyptian* cotton is supposed to be indigenous to that country. It is characterized by a fine golden color, and great toughness and tensile strength. It is, however, shorter and coarser than the Gallini cotton. In length of staple it varies from $1\frac{1}{2}$ to $1\frac{1}{8}$ ins., with a mean of 1.31 ins.; the mean diameter is 0.000738 in. *African* cottons are all derived from the *herbaceum* species. These cottons have a slight brownish tint, and always contain a large amount of short fibre. The fibres also vary much in diameter and thickness of the tube-walls, and many exhibit a transparent appearance under the microscope. Yarns made from these cottons are always uneven on the surface. The length of staple varies from $1\frac{3}{8}$ to $\frac{7}{8}$ ins., with an average of 1.03 ins.; the mean diameter is 0.00082 in. *Hingunghat* cottons are Indian varieties; the quality of these varies with the soil and climate of the province in which they are grown. As a rule, they are of rather inferior grade; the best variety is the *Surat* cotton. Under the microscope the Hingunghat cotton shows much variation in diameter, although it possesses fewer twists than the better grades of cotton, yet, unlike the African varieties, it shows very few fibres without any convolutions at all. In length of staple it varies from $1\frac{3}{8}$ to $\frac{7}{8}$ ins., with a mean of 1.03 ins.; the average diameter is 0.00084 in. *Broach*, *Tinnevely*, *Dharwar*, *Oomrawuttee*, *Dhollerah*, *Western Madras*, *Comptah*, *Bengal*, and *Scinde* are other varieties of Indian cotton, all belonging to the *herbaceum* species. They have the same general properties and

staple as the preceding, becoming more and more inferior, however, in the order of the list given.

Gossypium hirsutum.—*White Egyptian*, unlike the brown variety described above, is not indigenous, but was transplanted from America. In length of staple it varies from $1\frac{3}{8}$ to $1\frac{1}{8}$ ins., with a mean of $1\frac{1}{4}$ ins.; the diameter averages 0.00077 in. This cotton shows a large number of fibres having but a partially developed spiral form. *Orleans* cotton is the typical American variety, and is perhaps the best of the American cottons. The fibres are quite uniform in length, having an average staple of about 1 in. and a mean diameter of 0.00076 in. It is almost pure white in color. *Texas* cotton much resembles the foregoing, but has a slight golden color; its length and diameter of staple are the same. *Upland* cotton is another very similar variety; its length of staple, however, is somewhat less than the foregoing, averaging but $1\frac{1}{8}$ in. Its twist is rather inferior to the *Orleans*, and it shows a larger number of straight fibres. *Mobile* cotton is the most inferior of the American varieties; it varies in length of staple from 1 to $\frac{3}{4}$ in., with a mean of $\frac{7}{8}$ in.; its average diameter is 0.00076 in. It shows about the same microscopic appearance as upland cotton. *Santos* cotton comes from Brazil; it is not much in demand on account of its inferior quality.

Gossypium peruvianum.—*Rough Peruvian*; this cotton has a light creamy color and is rather harsh and hairy in feel. In length of staple it varies from $1\frac{7}{8}$ to $1\frac{1}{8}$ ins., with a mean of 1.28 ins.; its mean diameter is about 0.00078 in. Most of the fibres are only partially twisted. *Smooth Peruvian* has a soft, smooth feel, but the staple is not so strong as the preceding. The length is about the same as the foregoing, as is also the diameter. *Per-nambuco* has a slight golden color and feels harsh and wiry. It is a variety of Brazilian cotton. It is rather regular in length of staple, the mean being $1\frac{1}{4}$ ins. The diameter averages 0.00079 in. Under the microscope the twists appear regular and well-defined. *Maranhams* cotton is very similar to the preceding in microscopic appearance and length and diameter of staple. *Ceara* is a Brazilian cotton, rather inferior to the others by reason of its considerable variation in length of staple. *Maceio* is a

similar variety, but somewhat harsher. *West Indian* cottons nearly all belong to the *peruvianum* species; they are usually long in staple and harsh and wiry in feel, and only of moderate strength. The length is quite uniform and averages $1\frac{1}{4}$ ins. The diameter varies considerably, but has an average of about 0.00077 in. The twist is short and very uniform, surpassing even sea-island in this respect.

Chinese cotton, also known as *Nankin* cotton, is classified as *G. religiosum*; it yields a naturally colored fibre, being rather dark yellowish brown. It grows principally in China and Siam.

3. Vegetable Silks.—Besides the cotton derived from the *Gossypium* family, there is a similar seed-hair fibre obtained from what is known as the cotton-tree or *Bombax cotton*, or vegetable down, the growth of which is confined almost exclusively to tropical countries.* The fibre is soft, but rather weak as compared with ordinary cotton; in color it varies from white to yellowish brown, and it is quite lustrous. Physically *Bombax* cotton differs from true cotton in not possessing any spiral twist and showing irregular thickenings of the cell-wall. In its chemical constitution it differs from the other cotton by containing a certain amount of lignified tissue; consequently it gives a yellow coloration when treated with anilin sulphate or iodine and sulphuric acid, and by these tests may be distinguished from true cotton.†

* There are a number of varieties of vegetable down, of which the following are the principal:

Bombax ceiba, from tropical America.

Bombax heptaphyllum, from same countries.

Bombax malabaricum, from south Asia and Africa.

Gossypium cochlospermum, from India.

Ochroma lagopus, from the West Indies.

Chorisia speciosa, from South America.

Eriodendron anfractuosum, or *Bombax pentandrum*, from south Asia.

The *Rama limpa* cotton of Brazil is obtained from *Bombax heptaphyllum*. The product known in Holland as *kapok* is obtained from *B. pentandrum*. The *Edredon végétal* and *Pattes de lièvre* of the French trade are products of *Ochroma lagopus*. The *Ouate végétal* is a mixture of *Bombax*, *Ochroma*, and *Chorisia* varieties.

† The microscopic characteristics of vegetable down are as follows: The fibre consists of a single hair possessing a conical shape; the base is frequently

Another seed-hair which is utilized as a fibre is *Asclepias cotton*, which is also known as *vegetable silk*, as the fibres possess a very high lustre. This cotton, however, is quite brittle in nature and possesses but little strength; hence attempts at spinning it have not proved very successful. As this fibre is also somewhat lignified, it may be distinguished from true cotton by the application of the above-mentioned tests. When examined under the microscope it shows thickened streaks in the cell-wall which serve to distinguish it from *Bombax* cotton.*

swollen or lace-like in structure. The length varies from 1 to 3 cm. The cross-section is circular, so that the fibres are not flat as with cotton. The contents of the inner canal consist of air and a dried-up protoplasmic membrane. As all vegetable downs are more or less lignified, their fibres swell but slightly when treated with Schweitzer's reagent. The thickness of the fibres varies from 20 to 50 μ .

Höhnelt gives the following description of the chief varieties of vegetable down:

1. *Bombax ceiba*; length 1 to 1.5 cm. *B. malabaricum* has a fibre-length of 1 to 2 cm., and *B. heptaphyllum* from 2 to 3 cm. The last is by far the longest and strongest variety, and is sometimes used in spinning. The diameter of the *Bombax* fibres varies from 19 to 43 μ , with an average of 25 μ .

2. The hairs of *Eriodendron anfractuosum* are very similar to the preceding, and it is difficult to distinguish between them.

3. The fibres of *Ochroma lagopus* are 0.5 to 1.5 cm. in length, and are thicker at the middle than at the ends. The cell-wall is quite thick, and the fibres are more highly lignified than the foregoing.

Pulu fibre can also be classed under the general name of vegetable down. It is the hair obtained from the stems of fern-trees, more especially the *Cibotium glaucum* (from Sandwich Islands). The fibres are lustrous, of a golden-brown color, very soft and not very strong. They are about 5 cm. in length, and are composed of a series of very flat cells pressed together in a ribbon-like form. The fibre is only employed as a stuffing material and is never woven.

* There are several varieties of vegetable silks, chief among which are the following: *Asclepias curassavica*, from the West Indies; *Calotropis gigantea*, from south Asia and Africa; *Marsdenia*, from India; *Beaumontia grandiflora*, from India; *Strophanthus*, from Senegal. True vegetable silks as a rule may be recognized as follows: They are 4 to 6 cm. in length; possess a silky lustre; in color are white to yellow or reddish yellow; and are stiff. Their thickness is sometimes as much as 80 μ , but more generally 35 to 60 μ . The fibre is relatively thin-walled, but shows frequently on the inside several thickened longitudinal ridges, which are sometimes very apparent and at others scarcely noticeable. The ridges are semicircular in cross-section, though sometimes flat and broad. The ridges give the cell-wall the appearance of being uneven in thickness. The ridges form the chief microscopical feature of vegetable silk, and serve to distinguish these fibres from vegetable downs, which are otherwise very similar. The cross-section of the fibre is circular, and the cell-wall is lignified.

Cotton-silk is a seed-fibre which appears to be more or less identical with the foregoing. It is derived from an Indian plant botanically classified as *Salmalia*, a genus of *Malvaceæ*; the plant is a rather large tree, attaining the height of 70 to 80 ft. Although the fibre is very beautiful in appearance, having the texture and lustre of silk, it is not suitable for purposes of spinning, as its tensile strength is quite low. Under the microscope the fibres appear as thin, smooth, transparent tubes without the longitudinal markings of the silk fibre, and differing from cotton in not showing the twists and irregularities of that fibre, and in not being flattened but cylindrical in appearance. Cotton-silk may be readily distinguished from silk by igniting a fibre in a flame, when the former will burn with great rapidity, whereas silk will fuse and give off the characteristic odor of a burning animal fibre. Cotton-silk is evidently a form of cellulose fibre; its silky appearance being due to the delicacy and thinness of the cell-walls and their smooth surface. It is very sensitive to the action of dilute acids; towards dyestuffs it behaves like cotton, not combining with the basic colors except after a previous mordanting. There are several other plants which yield seed-hairs, which, as a rule, are not of much value for purposes of spinning and weaving; but they find rather extensive use for upholstery purposes and twines. As a rule, these fibres are colored red by phloroglucol and hydrochloric acid, and yellow with aniline sulphate, showing the presence of lignified tissue. Usually the fibres are somewhat yellow in color and possess considerable lustre.

CHAPTER X.

THE PHYSICAL STRUCTURE AND PROPERTIES OF COTTON.

1. Physical Structure.—Physically the individual cotton fibre consists of a single long cell, with one end attached directly to the surface of the seed. While growing, the fibre is round and cylindrical, having a central canal running through it; but after the enclosing pod has burst, the cells collapse and form a flat ribbon-like fibre, which shows somewhat thickened edges under the microscope. The juices in the inner tube, on the ripening of the fibre, are drawn back into the plant, or dry up, and in doing so cause the fibre to become twisted into the form of an irregular spiral or screw-like band.* Fibres that have not ripened differ somewhat in these characteristics, being straight and having the inner canal stopped up, in consequence of which they do not spin well and are difficult to dye, showing up as white specks in the finished goods; this is known as *dead cotton*. The presence of an inner canal in the cotton fibre no doubt adds to its absorptive power for liquids, and its capillary action allows cotton to retain salts, dyestuffs, etc., with considerable power; but too much importance in this respect must not be attributed to the canal, for when cotton is mercerized the canal is almost entirely obliterated by the walls being squeezed together, and yet mercerized cotton is much more absorptive of dyes, etc., than ordinary cotton. The capillarity of the cotton fibre is no doubt principally due to the existence of minute pores which run from the surface inward. The crystallization of salts in these pores and in the central canal may lead to the rupturing of the fibre, as, for instance, when filter-paper is made by disintegrating cotton fibres by saturating them with water and then freezing them.

The cotton fibre is rather even in its diameter for the greater

* The number of twists in the cotton fibre in the raw state is said to be from 300 to 500 per inch.

part of its length, though it gradually tapers to a point at its out-growing end. The different varieties of cotton show considerable variation, both in length and diameter of fibre; in sea-island cotton the length is nearly 2 ins., while in Indian varieties it is often less than 1 in. The diameter varies from 0.00046 to 0.001 in.; the longest fibres having the least diameter.

The following table of the length and diameter of different varieties of cotton fibres has been collated as a mean of several observers:

Name of Cotton.	Length in mm.	Diameter in μ .	Name of Cotton.	Length in mm.	Diameter in μ .
<i>Sea-island</i>	41.9	9.65	<i>West Indian</i>	32.3	19.6
Edisto.....	46.6	.....	<i>American</i>.....	.....	20.9
Wodomalam.....	39.0	.....	Orleans.....	27.0	19.2
John Isle.....	39.3	.....	Upland.....	29.5	19.4
Florida.....	45.7	16.18	Texas.....	24.3	16.6
Fitschi.....	48.7	16.7	Mobile.....	25.0	19.4
Tahiti.....	42.9	16.3	Georgia.....	25.4	10.3
Peruvian.....	38.9	15.3	Mississippi.....	24.2	3.4
<i>Egyptian</i>	32.1	16.7	Louisiana.....	25.0	.....
Gallini.....	37.2	17.1	Tennessee.....	25.1	15.0
Brown.....	34.4	18.7	<i>African</i>	27.6	20.8
White.....	31.8	19.5	<i>Indian</i>.....	.....	19.3
Smyrna.....	28.5	22.8	Hingunghat.....	28.3	20.0
<i>Brazilian</i>.....	.....	18.8	Dhollerah.....	28.2	21.5
Maranham.....	28.8	20.4	Broach.....	20.9	21.8
Pernambuco.....	35.2	20.0	Tinnevelly.....	23.0	21.0
Surinam.....	30.2	.....	Oharwar.....	23.6	21.0
Paraiba.....	29.7	.....	Oomrawuttee.....	24.1	21.5
Ceara.....	28.1	20.0	Comptah.....	23.8	21.5
Maceo.....	29.3	.....	Madras.....	21.8	21.8
<i>Peruvian rough</i>	29.9	21.5	Scinde.....	20.4	21.3
Smooth.....	30.0	21.5	Bengal.....	25.7	23.7
<i>Agerian</i>	37.5	.....	<i>Chinese</i>	21.4	24.1

Evan Leigh (*Science of Modern Cotton Spinning*) gives the following summary of the length and diameter of cotton fibres:

Place of Growth.	Kind of Cotton.	Length in Ins.			Diameter in Ins.		
		Min.	Max.	Mean.	Min.	Max.	Mean.
United States ..	New Orleans. . .	0.88	1.16	1.02	.000580	.000970	.000775
Sea-islands . . .	Long stapled. . .	1.41	1.80	1.61	.000460	.000820	.000640
South America.	Brazilian.....	1.03	1.31	1.17	.000620	.000960	.000790
Egypt.....	Egyptian.....	1.30	1.52	1.41	.000590	.000720	.000655
India.	Native.....	0.77	1.02	0.89	.000649	.000940	.000844
	American seed..	0.95	1.21	1.08	.000654	.000996	.000825
	Sea-island seed .	1.36	1.65	1.50	.000596	.000864	.000730

Hannan gives the following varieties and qualities of cotton to be met with in commerce:

Types.	Variety.	Length Ins.	Diameter, Ins.	Counts.	Use.	Properties.
<i>Sea-island</i> . .	Edisto.	2.20	.00063	300-400	Warp or weft	Long, fine silky, and of uniform diameter
	Florida.	1.85	.00063	150-300	do.	Shorter, but similar to above
	Fiji.	1.75	.00063	100-250	do.	Less uniform in length, but silky and cohesive
	Tahiti.	1.80	.00063	"	do.	Good, fine, and glossy staple
<i>Egyptian</i> . .	Brown.	1.50	.00070	120-down	do.	Long, strong, high- ly endochromatic
	Gallini.	1.60	.00066	250-down	Warp	High class staple of good strength
	Menouffieh. . .	1.50	"	200-down	Weft	Of good staple and lustre
	Mitaiffi.	1.25	"	100	Warp or weft	Fairly good staple
<i>Peruvian</i> . .	White.	1.00	.00078	70	do.	Pearly white, good long staple
	Rough.	1.25	.00078	50-70	Warp	Strong, wooly, and harsh staple
	Smooth.	1.00	"	"	Weft	Less wooly, and softer staple
	Red.	1.25	"	40-50	Warp	Color weaker and harsher than brown Egyptian
<i>Brazilian</i> . .	Pernams.	1.50	.00079	50-70	Warp	Strong and wiry
	Maranhams. . .	1.15	"	50-60	do.	Harsh and wiry
	Ceara.	1.15	"	60	Weft	Good, white, and cohesive staple
	Paraiba.	1.20	"	50-60	Warp or weft	Fairly strong, harsh, of good color
<i>American</i> . .	Rio Grande. . .	1.15	"	40-50	Weft	Soft, white, and harsh staple
	Maceio.	1.20	.00084	40-60	Warp or weft	Soft, pliable, and good for hosiery
	Santos.	1.30	"	50-60	Weft	Exotic from Ameri- can seed, white and silky staple
	Bahia. . . . .	.....	.....	40-50	Warp or weft	Fairly strong, but harsh and wiry
<i>American</i> . .	Orleans.	1.1	.00077	34-46	Warp or weft	Medium length, pearly, white
	Texas.	1.05	"	32-40	do.	Similar to above, rather harsher and more glossy
	Allanseed. . . .	1.20	"	50-60	Warp	Good, white, long; blends with brown Egyptian

Types.	Variety.	Length, Ins.	Diameter, Ins.	Counts.	Use.	Properties.
<i>American...</i>	Mobile.	1.00	.00076	40-50	Warp or weft	Even-running staple, soft and cohesive
	Norfolks.	1.00	"	40-50	Weft	Used for Oldham counts of 50's
	St. Louis.	0.90	"	30-32	Warp	Staple irregular, glossy, but short
	Ronoaks.	0.90	"	30-34	do.	A white and strong staple
	Boweds. ....	.....	.....	36	Weft	Similar to uplands
	Benders.	1.10	.00077	60	Warp	Strong, creamy or white, for Turkey-red dyes
	Memphis.	1.00	"	40-50	do.	Bluish white, for extra hard twists
	Peelers.	1.25	"	60-80	Weft	Long, silky, fine staple; adapted for velvets, etc.
	Uplands.	1.00	"	36-40	do.	Glossy when clean, apt to be dull, sandy, and leafy
	Alabama.	0.90	"	26-30	Warp or weft	Short staple, of less strength, varying color
	Linters. ....	.....	.....	8-10	Weft	Short stapled gin waste
	Tennessee.	0.90	"	28	Warp or weft	Of varying length and color
<i>Greek.</i>	Smyrna.	1.25	.....	36-40	Warp	Harsh and strong, adapted for double yarns.
<i>African.</i>	Lagos.	0.80	.....	20-26	Weft	Dull and oil-stained; irregular in length and strength
<i>West Indian</i>	Carthagen.	1.50	.....	26	Warp	From exotic seeds; fairly strong
	La Guayran.	1.20	.....	40	Warp or weft	Irregular and short, but silky staple
<i>China.</i>	China.	1.00	.....	30	Weft	Harsh, short, and white
<i>Australian.</i>	Queensland.	1.75	.00066	120-200	Warp or weft	Long, white, silky, fine diameter
<i>East Indian</i>	Oomrawuttee.	1.00	.00083	26-32	Warp	Short, strong, and white
	Hingunghat.	1.00	"	28-36	Weft	Best white Indian staple
	Comptah.	1.05	.....	.....	Warp or weft	Generally dull, and charged with leaf
	Broach.	0.90	.....	28-36	Weft	Like Hingunghat, gives good white weft
	Dharwar.	1.00	.....	28	Warp	Exotic from American seeds

Types.	Variety.	Length, Ins.	Diameter, Ins.	Counts.	Use.	Properties.
<i>East Indian.</i>	Assam.	0.50	.....	15-20	Warp	White, but harsh. To blend with other cottons
	Bengals.	0.80	.....	20-30	Warp or weft	Dull and generally charged with leaf
	Bilatee.	0.50	.....	10-20	do.	Weak, brittle, and coarse
	Dhollerah. ...	0.70	.....	15-20	do.	Strong, dull, and co- hesive
	Surat.	0.60	.....	10-15	do.	Dull and leafy, often stained
	Scinde.	0.50	.....	to 10	do.	Very strong, dull, short, and poor staple
	Tinnevelly. ...	0.80	.....	24-30	do.	Lustrous white, soft, and adapted for hosiery
	Bhownuggar	1.00	.....	28-30	Warp	White when clean; often leafy and dirty
	Cocoanada. ...	0.70	.....	10-14	Brown weft	Brown and dull; used as quasi- Egyptian
	Bourbon.	1.00	.....	30	Weft	Exotic; of good staple; scarce
	Khandeish. ...	0.80	.00083	20-26	Warp or weft	Similar in class to Bengal
	Madras or Westerns	0.70	.....	15-20	do.	Used for low yarns in coarse towelling, etc.
	Rangoon.	0.60	.....	to 10	Warp or weft	Weak, dull, often stained and leafy
	Kurrachee. ...	0.90	.....	28	do.	Fairly strong, dull, and leafy
<i>Italian.</i>	Calabria.	0.90	.....	26-28	do.	Fairly strong, irreg- ular and dull, leafy
<i>Turkey.</i>	Levant.	1.25	.00077	36-40	Warp	Harsh, strong, and white

Höhnel gives the following table for the thickness of different varieties of cotton:

	mm.
<i>North American:</i>	1000
Sea-island.	14
Louisiana and Alabama.	17
Florida.	18
Upland and Tennessee.	19
<i>Southern and Central American.</i>	15-21
Average.	19

	<u>mm.</u> 1000
<i>East Indian:</i>	
Dollerah and Bengal.....	20
Madras.....	28
<i>Chinese:</i>	
Nankin.....	25-40
<i>Egyptian:</i>	
Macco.....	15
<i>Levianthan.</i>	24
<i>European:</i>	
Spanish.....	17
Italian.....	19

According to Wiesner the thickest part of the cotton fibre is not directly at the base, but more or less towards the middle. He gives the following measurements of thickness at different parts of the fibre:

Position.	<i>G. arboreum</i> , 25 mm. long. <u>mm.</u> 1000	<i>G. acuminatum</i> , 28 mm. long. <u>mm.</u> 1000	<i>G. herbaceum</i> , 25 mm. long. <u>mm.</u> 1000
Point	0	0	0
1	8.4	4.2	4.2
2	21	21.6	5.8
3	29	16.8	10.0
4	25	29.4	16.8
5	29	17.0	21.0
6	25	21.1	16.9
7	21	21.1	21.0
Base	17	21.0	16.8
Mean	19.5	16.9	12.5

The length of the cotton fibres attached to a single seed is by no means constant. The longest fibres usually appear at the crown of the seed, while the shortest occur at the base. There is also frequently an undergrowth of very short fuzzy fibres. In ginning, the very short fibres are ordinarily not removed from the seed, but always more or less do come in with the ginned cotton. These short fibres are termed "neps," and their presence in any considerable amount materially affects the commercial value of the cotton. This short undergrowth of neps appears to be made up of incompletely developed or immature fibres, though neps may also arise through excessive breaking of fibres by imperfect manipulation in the carding and spinning processes.

Bowman (*Structure of the Cotton Fibre*) gives the following table showing the extreme variation in the length and diameter of different kinds of cotton:

Cotton.	Variation in Length.	Variation in Diameter.
American (Orleans).	0.28 in.	0.000390 in.
Sea-island	0.39 "	0.000360 "
Brazilian	0.28 "	0.000340 "
Egyptian	0.22 "	0.000130 "
Indian (Surat)	0.25 "	0.000391 "

Bowman calls attention to the fact that Egyptian cotton is the most regular in both length and diameter; while sea-island cotton, though possessing the greatest length and fineness of staple, also exhibits the greatest variation. It is also noticeable that the variation in the diameter is proportionately very much larger than the variation in the length. Bowman also gives an interesting comparison of the size of the individual cotton fibre with objects of common experience. If a single fibre of American cotton were magnified until it becomes 1 in. in diameter, it would be a little over 100 ft. long, while a sea-island fibre of the same diameter would be about 130 ft. It requires from 14,000 to 20,000 individual fibres of American cotton to weigh 1 grain, hence there are about 140,000,000 in each pound, and each fibre weighs on an average only about 0.00006 gr. If the separate fibres contained in one pound were placed end to end in a straight line, they would reach 2200 miles.

Höhnel gives the following table of the different varieties of cotton arranged according to their length of staple:

<i>Gossypium barbadense</i>	(Sea-island).....	4.05 cm.
" "	(Brazilian).....	4.00 "
" "	(Egyptian).....	3.89 "
" <i>vitifolium</i>	(Pernambuco).....	3.59 "
" <i>conglomeratum</i>	(Martinique).....	3.51 "
" <i>acuminatum</i>	(Indian).....	2.84 "
" <i>arboresum</i>	(Indian).....	2.50 "
" <i>herbaceum</i>	(Macedonian).....	1.82 "
" "	(Bengal).....	1.03 "

From its behavior with a solution of ammonio-copper oxide, the cotton fibre appears to consist of four distinct parts structurally. When treated with this solution and examined under the microscope, the fibre is seen to swell, but not uniformly; it seems that at regular intervals there are annular sections which do not swell.* The result is that the fibre assumes the form of a distended tube tied at intervals somewhat after the manner of a string of sausages. Soon the main portion of the fibre begins to dissolve, whereupon the walls of the central canal are seen quite prominently; the dissolving action proceeds rapidly, but apparently there is a thin cuticular tissue surrounding the fibre which resists the action of the solvent for a much longer time than the inner portion. The walls of the central canal also resist the action of the liquid to even a greater extent than the external tissue; the annular contracted ligatures in the fibre also persist after the rest of the fibre has dissolved. Thus we have four structural parts made evident (see Fig. 37):

(a) The main cell-wall, probably composed of pure cellulose, and rapidly and completely soluble in the reagent.

(b) An external cuticular fibre, probably of modified cellulose, and more resistant to the action of the reagent.

(c) The wall of the central canal, which resists the solvent power of the reagent even more than the cuticle.

(d) The annular ligatures surrounding the fibre at intervals, which persist even after the canal-walls have dissolved.

O'Neill (in 1863) first pointed out this complex structure of the cotton fibre. He says: "I believed that in cotton-hairs I could discern four different parts. First, the outside membrane,

* Höhnel considers these ligatures as merely parts of the cuticle; he explains their formation by the fibre swelling so considerably as to rupture the undisturbed cuticle, which in places adheres to the fibre in the form of irregular shreds which are visible only with difficulty. In other places where the rupture occurs obliquely to the length of the fibre, the cuticle becomes drawn together in annular bands surrounding the fibre, while between these rings the much-distended cellulose protrudes in the form of globules. The inner membrane or canal which persists after the rest of the fibre has dissolved is an exceedingly thin tissue of dried protoplasm which was contained in the living fibre. On bleached cotton the cuticle may be almost entirely lacking, and hence such fibres will not exhibit the characteristic appearance above mentioned.

which did not dissolve in the copper solution. Second, the real cellulose beneath, which dissolved, first swelling out enormously and dilating the outside membrane. Thirdly, spiral fibres, apparently situated in or close to the outside membrane, not readily soluble in the copper liquid. These were not so elastic as the outside membrane and acted as strictures upon it, producing bead-like swellings of a most interesting appearance; and fourthly, an insoluble matter, occupying the core of the cotton-hair, and which resembled very much the shrivelled integument in the interior of quills prepared for making pens." He also notes that the insoluble outside membrane was not evident on bleached cotton, hence concluding that either it had been dissolved away, or some protecting resinous varnish had been removed, and then it became soluble. He also obtained the same general results by treatment with sulphuric acid and chloride of zinc in place of the ammonio-copper solution.

According to Butterworth, who observed the cotton fibre treated with the ammonio-copper solution under a magnification of 1600 diameters, there are spiral threads apparently crossing and tightly bound round the fibre at irregular distances, also spiral threads passing from one stricture to another; the core of the fibre has a spiral form, and in cross-section shows the presence of concentric rings (see Figs. 35 and 36).

There appears to be some difference in the action of ammonio-copper solution on fibres of different physiological structure. Immature or unripe fibres dissolve readily without exhibiting any structural differences. The tubular-shaped fibres swell out as a whole and finally dissolve without showing any structural modifications, except that in many cases an inner core is left.

Examination with the highest microscopic powers has not shown any cellular structure pertaining to the cellulosic contents of the cotton fibre; it is probably composed of fine layers superimposed one upon the other.

2. Microscopical Properties.—The microscopical characteristics of the cotton fibre are so pronounced as to readily differentiate it from all others. As already noted, it presents the appearance of a flat, ribbon-like band more or less twisted on its longitudinal

axis (see Fig. 33). The cell-wall is rather thin and the lumen occupies about two-thirds of the entire breadth and shows up

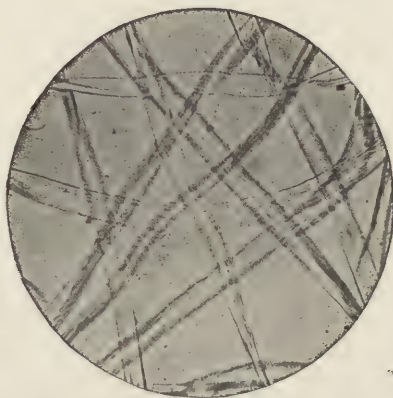


FIG. 33.—Unripe Cotton Fibres ($\times 350$).

Showing a flat, ribbon-like form and thin and almost transparent appearance.

very prominently in polarized light. Between its thickened edges the fibre exhibits the appearance of a finely granulated surface. Fibres of dead cotton, or those which have not reached their full maturity, are seldom twisted spirally and do not have a lumen, but are thin, transparent bands (see Fig. 34).

Microscopically cotton fibres differ considerably among themselves, but in general may be divided into four classes:

(a) Fibres exhibiting a smooth, straight, flat appearance with no suggestion of internal structure. This includes immature cotton fibres and also fibres which have overripened by not being picked until some time after attaining full maturity. The external wall of the fibre is very thin.

(b) Fibres exhibiting a normal appearance through some portions of their length, and in other parts a structureless appearance as in (a). This may be termed "kempy" fibre; the solid, tubular portion of the fibre is particularly resistant to the absorption of liquids and dyestuffs, and consequently remains uncolored while the rest of the fibre is dyed.

(c) Straight, tubular fibres exhibiting a well-defined internal structure and a transparent cell-wall of varying thickness.

(d) Normal structure of twisted, band-like form.

In cross-section the immature fibres show only a single line with no structure, and but little or no indication of an internal opening. The mature fibre is thicker in cross-section and exhibits a central opening.

The most characteristic of the microchemical reactions for cotton is that with ammoniacal copper solution, already described. With bleached cotton the external cuticle may be absent, and hence such a fibre may not show any distension.

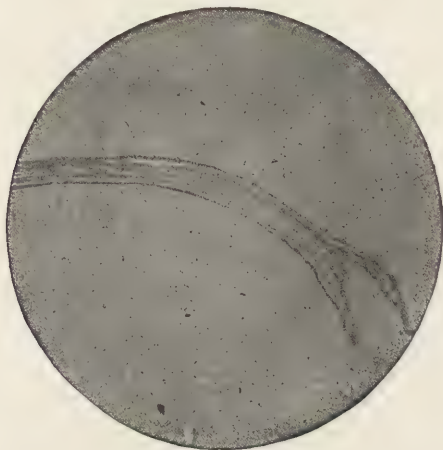


FIG. 34.—Root of Cotton Fibre ($\times 350$).

Showing the irregular fracture caused by the fibre being torn from the seed; at the broad, flat portion of the base of the fibre may also be seen the longitudinal wrinkles and the cross-fractures of the cuticle.

With iodine and sulphuric acid the cotton fibre becomes blue in color, though the cuticle remains colorless. Tincture of madder gives an orange color; fuchsin produces a red color which is destroyed by the addition of ammonia. Flax does not show this latter reaction, hence this serves as a chemical means of distinguishing between cotton and linen. Anhydrous stannic chloride gives a black color, and sulphuric acid dissolves the cotton fibre rapidly.

3. Physical Properties.—The natural, spiral-like twist present in the cotton fibre causes the latter to be especially adaptable to purposes of spinning. The spinning qualities of the cotton

fibre, however, depend not only on the nature and amount of twist which causes the individual fibres to lock themselves firmly

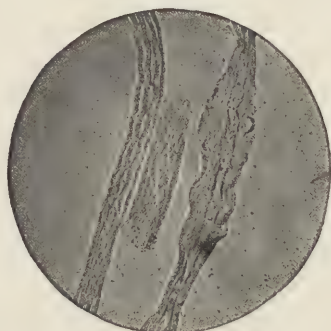


FIG. 35.—Cotton Fibre, Swollen with Schweitzer's Reagent ($\times 500$).
Showing the walls of the internal canal, and the spirally fibrous structure of the cellulose wall.

together, but also on the length and fineness of staple. These three qualities in general will designate the character and fineness

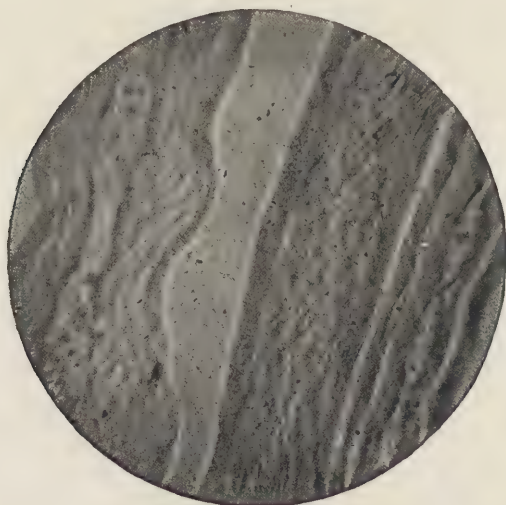


FIG. 36.—Portion of Fig. 35 very highly magnified ($\times 2000$).
The structure of the cellulose is here plainly apparent.

of yarn which may be spun from any sample of cotton. Sea-island cotton lends itself to the spinning of very fine yarns, being

spun to even 300's (that is, 300 hanks of 840 yds. each would weigh 1 lb.), and in an experimental manner this cotton has even been spun as fine as 2000's.

In its tensile strength cotton stands between silk and wool; whereas, in elasticity, it is considerably below either of the other two fibres. The breaking strain of cotton will vary from 2.5 to 10 grams, depending on the fineness of staple; the finer the fibre, the less will be its breaking strain.

Cotton is less hygroscopic than either wool or silk; under normal conditions it will contain from 7 to 8 per cent. of hygroscopic moisture, though in a very moist atmosphere this may be considerably increased.

The hygroscopic quality of cotton (and, in fact, other vegetable fibres as well) has much to do with its proper condition during

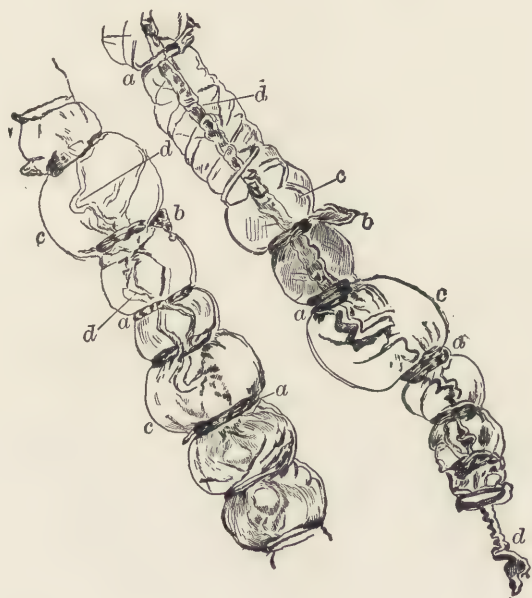


FIG. 37.—Appearance of Cotton Fibre on Treatment with Schweizer's Reagent. (Witt.)

a, transverse ligatures of disrupted cuticle; *b*, irregular shreds of cuticle torn apart; *c*, swollen mass of cellulose; *d*, walls of internal canal.

the various processes of spinning and finishing. It also has an influence on the commercial valuation of the raw material, as

the amount of hygroscopic moisture varies with atmospheric conditions, and it is important to have a normal standard of reference (see wool conditioning). Its influence on spinning is even greater, and proper conditions of atmospheric moisture must be maintained in the spinning-room in order to achieve the best results; the spinning properties of raw cotton, however, are also affected by other substances associated with the cellulose of the fibre, but it is without question that the physical condition of cotton is largely influenced by its content of hygroscopic moisture, and this should be delicately adjusted by the spinner to meet the conditions of his work. The mechanical treatment of woven textile materials in finishing processes, such as mangling, beetling, calendering, etc., is also dependent for good results to quite an extent on the hygroscopic condition of the fibre; the amount of moisture present during the finishing operations, together with the method and degree of drying, should be carefully studied.*

The following table shows the results of experiments on the tensile strength of different varieties of cotton:

Cotton.	Mean Breaking Strain.	
	Grains.	Grams.
Sea-island (Edisto)	83.9	5.45
Queensland.....	147.6	9.59
Egyptian.....	127.2	7.26
Maranham.....	107.1	6.96
Bengal.....	100.6	6.53
Pernambuco.....	140.2	9.11
New Orleans.....	147.7	9.61
Upland.....	104.5	6.79
Surat (Dhollerah).....	141.9	9.22
Surat (Comptah).....	163.7	10.64

* In testing the influence of moisture on the strength of cotton material, the Industrial Society at Mulhause reports as follows:

Normal strength of cloth.....	100
Saturated with moisture.....	104
Dried on hot cylinder.....	86
Again dampened.....	103

It would appear from these results that the alternate moistening and hot drying of cotton caused little or no deterioration in its strength.

The full tensile strength of the individual fibre, however, is not utilized in the spun yarn. Single yarns will give only about 20 per cent., or one-fifth, of the breaking strain calculated from the strength of the separate fibres; two-ply yarns give about 25 per cent.

The following table exhibits the comparative values of the tensile strength of different fibres. The "breaking length" refers to a length of thread which will break by reason of its own weight.

Fibre.	Breaking Length in Kilometers.	Tensile Strength, Kilograms per Square mm.
Cotton.	25.0	37.6
Wool.	8.3	10.9
Raw silk.	33.0	44.8
Flax fibres.	24.0	35.2
Jute.	20.0	28.7
China grass.	20.0	
Hemp.	30.0	45.0
Manila hemp.	31.8	
Cocoanut fibre.	17.8	29.2
Vegetable silk.	24.5	

When cotton is purified from its adhering waxy and fatty matters, it becomes remarkably *absorbent*. This quality is explained on the supposition that the ripe cotton fibre is made up of a series of tissues of cellulose, separated from each other by intercellular matter, in this way forming a series of capillary surfaces which are capable of exerting considerable capillary force upon any liquid in which the fibre may be immersed. Dry cotton also appears to be remarkably absorptive of gases; it is said that the fibre can absorb 115 times its volume of ammonia at the ordinary atmospheric pressure.

CHAPTER XI.

CHEMICAL PROPERTIES OF COTTON; CELLULOSE.

1. Chemical Constitution.—In its chemical composition, cotton, in common with the other vegetable fibres, consists essentially of cellulose. On the surface there is a protecting layer of more or less wax and oily matter, and also in the fibre there is a trace of pigment, which in some varieties of cotton becomes quite emphasized. The removal of these substances is the object of the boiling-out and bleaching processes to which cotton is subjected prior to its dyeing and printing. In reality, the purified cotton fibre as it exists in bleached material is practically pure cellulose, and this compound alone appears to be essential to its structural organization.

The natural impurities present in the raw cotton fibre amount to about 4 to 5 per cent., and consist chiefly of pectic acid, coloring-matter, cotton-wax, cotton-oil, and albuminous matter. The fibre gives about 1 per cent. of ash on ignition.* The oil present in the fibre appears to be identical with cottonseed-oil, and is probably obtained from the seed to which the fibre is attached. The cotton-wax serves as a protective coating for the fibre and makes it water-repellent, as is evidenced by the long time it requires for raw cotton to be wetted out by simply steeping in water. This wax appears to be closely analogous to carnaüba wax; it is not soluble in alkalis, though it may be gradually emulsified by a long-continued boiling in alkaline solutions, on which

* Bowman is of the opinion that considerable stress should be laid on the fact that the cotton fibre contains about 1 per cent. of mineral matter as an integral part of its constitution, and this no doubt has considerable influence on its structure and properties.

fact is based the "boiling-out" of cotton by the ordinary methods. Cotton-wax, however, appears to be readily soluble in sulphated oils, such as Turkey-red oil, and hence cotton may be rapidly and thoroughly wetted out by using a solution of such an oil. The coating of wax over the cotton fibre appears to influence its spinning qualities to a certain extent, as it requires, for instance, a rather elevated temperature to successfully spin fine yarns, in order probably to soften the waxy coating of the fibre.* The fatty acid present in cotton-wax has been found to be identical with margaric acid. The coloring-matter of cotton has been investigated and has been found to consist of two organic pigments, the one easily soluble in alcohol, and the other only dissolved by boiling alcohol. According to Schunck, the composition of these bodies from Nankin cotton is as follows:

	A.—Soluble in Cold Alcohol. Per Cent.	B.—Insoluble in Cold Alcohol. Per Cent.
Carbon.	58.22	57.70
Hydrogen.	5.42	5.60
Nitrogen.	3.73	4.99
Oxygen.	32.63	31.71

The composition of the analogous coloring-matters in American cotton is practically identical with the above.

Pectin compounds form the greater portion of the impurities present in cotton, and are probably rather complex in nature.

According to Dr. Schunck, American cotton contains about 0.48 per cent. of fatty matters, whereas East Indian cotton contains only 0.337 per cent.

Analysis of cotton-wax shows it consists of the following:

	Per Cent.
Carbon.	80.38
Hydrogen.	14.51
Oxygen.	5.11

* As the temperature falls the oily wax tends to become stiff and gummy, and prevents the proper drawing of the fibre; while its presence amongst the thin laminations of the cell-walls gives a greater elasticity to the fibre, and renders it less liable to sudden rupture. The gradual drying up of the more volatile portions of this oil in the fibre, leaving the remaining portion thicker and stiffer, may also, and probably does, account for the fact noticed by most spinners, that new-crop cotton seems to work better and makes less waste than as the season advances. (Bowman, "Cotton Fibre," p. 55.)

It fuses at 85.9°C ., and solidifies at 82°C ., hence it bears a close analogy to both cerosin, or sugar-cane wax, and carnaüba wax.

The quantity of ash (mineral matter) in raw bale-cotton will average considerably higher than that obtained from the purified fibre; this is due to adhering sand and dust which are nearly always present. The following table shows the amount of ash contained in samples of different varieties of cotton:

	Per Cent.
Dharwar.....	4.16
Dhollerah.	6.22
Sea-island.	1.25
Peruvian (soft).	1.68
“ (rough).....	1.15
Bengal.	3.98
Broach.....	3.14
Oomrawuttee.....	2.52
Egyptian (brown).....	1.73
“ (white).....	1.19
Pernam.....	1.60
American.....	1.52

When the amount of ash is found to be over 1 per cent. the excess may be considered as mechanically attached sand and dust. The true ash of the cotton fibre consists principally of the carbonates, phosphates, chlorides, and sulphates of potassium, calcium, and magnesium, as is exhibited by the following analysis of Dr. Ure:

	Per Cent.
Potassium carbonate.....	44.80
“ chloride.....	9.90
“ sulphate.....	9.30
Calcium phosphate.....	9.00
“ carbonate.....	10.60
Magnesium phosphate.....	8.40
Ferric oxide.....	3.00
Alumina and loss.....	5.00

The analyses of Davis, Dreyfus, and Holland, reported as a mean from twelve different varieties of cotton, show a little difference from the above analysis, especially in having present sodium carbonate as one of the constituents. The mean of these analyses is given as follows:

	Per Cent.
Potassium carbonate.	33.22
“ chloride.	10.21
“ sulphate.	13.02
Sodium carbonate.	3.35
Magnesium phosphate.	8.73
“ carbonate.	7.81
Calcium carbonate.	20.26
Ferric oxide.	3.40

The albuminous or nitrogenous matter present in cotton is only of very small amount, and doubtless consists of protoplasmic residue. Different varieties of cotton, on analysis, show the following percentages of nitrogen; some of this, however, may be derived from mineral nitrates which may be present in slight amount in the fibre (Bowman):

	Per Cent Nitrogen.
American.	0.030
Sea-island.	0.034
Bengal.	0.039
Rough Peruvian.	0.033
Egyptian (white).	0.029
“ (brown).	0.042
Mean.	0.0345

Analyses conducted by the U. S. Department of Agriculture give the average amount of nitrogen present in cotton as 0.34 per cent. As this differs very considerably from that obtained by Bowman, it may be possible that the latter must be multiplied by ten to obtain the correct figure.

Church and Müller have made careful analyses of raw cotton with the following results:

	I.	II.
Cellulose.	91.15	91.35
Hygroscopic water.	7.56	7.00
Wax and fat.	0.51	0.40
Nitrogen (protoplasm).	0.67	0.50
Cuticular tissue. ....	.....	0.75
Ash.	0.11	0.12

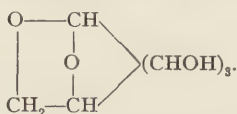
2. Cellulose.—This is one of the most important of the naturally occurring chemical compounds, as it forms the basis of all vegetable tissue. Chemically it consists of carbon, hydrogen,

and oxygen, and has the empirical formula $C_6H_{10}O_5$. It belongs to a class of bodies known as *carbohydrates*, and is closely related to the starches, dextrins, and sugars. Chemically considered, these compounds must all be regarded as alcohols containing aldehydic and ketonic groups. The word cellulose must not be taken as signifying a simple definite substance of unvarying properties, but rather as a generic term including quite a number of bodies of similar chemical nature. Like starch and other complex carbohydrates of organic physical structure, cellulose will vary somewhat in its properties, depending upon its source or derivation. As a class the celluloses exhibit certain chemical characteristics, by means of which they may be distinguished from associated bodies of allied chemical constitution. Physically they are colorless amorphous substances capable of withstanding rather high temperatures without decomposition. They are insoluble in nearly all of the usual solvents, but dissolve more or less completely in an ammoniacal solution of copper oxide (Schweitzer's reagent). Solution in this latter reagent apparently takes place without decomposition, as the cellulose may be reprecipitated unchanged therefrom by the addition of acids and various salts. In order to obtain pure cellulose for chemical purposes it is customary to treat cotton successively with dilute caustic alkali, dilute acid, water, alcohol, and ether. The purpose of this treatment is to remove all foreign and encrusting materials from the raw fibre, and possibly also to remove the thin, external cuticular membrane which may be chemically different from the rest of the tissue. The specific gravity or density of cellulose as obtained in the usual manner is about 1.5, and this also represents the density of cotton and most other plant fibres. Chemically considered, cellulose is a derivative of the open chain or paraffin series of hydrocarbons, and furthermore it exhibits the reactions of a saturated compound. As with the other carbohydrates, chemists have found it a matter of great difficulty to ascertain even approximately the true molecular formula of cellulose. Though its empirical formula is $C_6H_{10}O_5$, this in no way represents the true molecular complexity of the substance. From a study, however, of its various synthet-

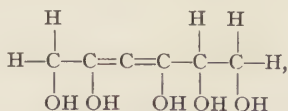
ical derivatives, with special reference to its esters, such as the acetates, benzoates, and nitrates, the provisional formula of $C_1 H_{20} O_{10}$ has been given to the cellulose molecule. The nature and position of the various organic groups present in this molecular formula, however, has yet to be worked out.*

In its chemical reactions cellulose is particularly inert, combining with only a few substances, and then only with great difficulty and under peculiar conditions. It is quite resistant to the processes of oxidation and reduction, and hydrolysis and dehydration. Concentrated sulphuric acid dissolves cellulose with the production of a viscous solution; dilution with water causes the precipitation of an amorphous substance known as *amyloid*, a starch-like body having the formula $C_{12} H_{22} O_{11}$, and like starch it is colored blue with iodine. On this reaction is based the method of testing for cellulose, by applying sulphuric acid and iodine. On boiling with dilute sulphuric acid, cellulose is

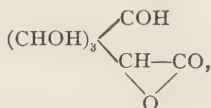
* Vignon has proposed to give cellulose the following constitutional formula:



This is based on a study of the highest nitrate of cellulose and the decomposition of the nitrate by alkalis with formation of hydroxypyruvic acid. The structure given, however, is more or less hypothetical in nature, and needs experimental confirmation in many particulars before it can be accepted without question. The older chemical configuration of cellulose given by Bowman,



is without any experimental reason for its existence, and the idea that it contains an unsaturated carbon grouping, $-\text{C}=\text{C}-$, has been proved erroneous. From a study of the osazones of oxycellulose, Vignon has ascribed to this latter body the constitutional formula of the group,



in union with varying proportions of residual cellulose.

converted into dextrin and glucose. On heating with acetic anhydride to 180°C ., cellulose is converted into an acetyl derivative having the formula $\text{C}_{12}\text{H}_{14}\text{O}_4(\text{OCOCH}_3)_6$. By the moderated action of concentrated acids and various acid salts, cellulose appears to undergo a process of hydration, being converted into a friable amorphous body known as hydrocellulose. This reaction is of importance in the carbonizing process for removing vegetable matter from woolen goods.

A concentrated solution of zinc chloride will dissolve cellulose on heating and digesting for some time. This solution has been employed industrially for the preparation of cellulose filaments which are subsequently treated with hydrochloric acid and washed for the purpose of removing the zinc salt; the thread is then carbonized and is employed for the carbon filament of incandescent electric lamps. A concentrated solution of zinc chloride in hydrochloric acid dissolves cellulose quite rapidly and in the cold. This latter method is useful in the laboratory for the study of celluloses, but as yet has received no technical application. By means of this solution it has been shown that the cellulose molecule does not contain any unsaturated carbon groups, for it exhibits no absorption of bromine. A solution of a ligno-cellulose, on the other hand, gives a marked bromine absorption, thus showing evidence of unsaturated carbon groups.

Cellulose is colored a deep violet by a solution of zinc chloride, and this reagent is employed as a delicate test for the presence of cellulose. The reagent may be best prepared by using 90 parts of a concentrated solution of zinc chloride, adding 6 parts of potassium iodide in 10 parts of water, and iodine until saturated.

When cellulose is treated with concentrated caustic alkalis it undergoes a change which may be crudely referred to as "mercerization," whereby a compound known as *alkali-cellulose* is formed, in which the molecular ratio of alkali to cellulose may be given as $\text{C}_{12}\text{H}_{20}\text{O}_{10}:\text{NaOH}$. When this body is treated with carbon disulphide a substance known as *cellulose thiocarbonate* or *xanthate* is formed. This body yields a very viscous solution with water and has been utilized for various technical purposes

(see *viscose*). Cellulose xanthate undergoes spontaneous decomposition, splitting up into cellulose hydrate, alkali, and carbon disulphide; this cellulose hydrate is also known as *regenerated cellulose*. This substance can also be precipitated by the addition of various salts, such as ammonium chloride. Alkali-cellulose also reacts with benzoyl chloride with the formation of *cellulose benzoate*. Another ester of cellulose is the *acetate*, which can be made by the action of acetic anhydride on cellulose heated in a sealed tube; regenerated cellulose can also be employed. By varying the conditions of treatment a number of different acetates have been prepared. The *tetracetate* has received a number of commercial applications for the production of films and for waterproofing. By the action of nitric acid under varying conditions a number of *cellulose nitrates* (improperly called nitrocelluloses) have been prepared, which have received numerous applications (see *pyroxylin*). Concentrated sulphuric acid reacts with cellulose to form at first a *cellulose sulphate*; this subsequently undergoes decomposition with a consequent hydrolysis of the cellulose molecule and the formation of amyloid.

Although cellulose is comparatively inert to the majority of chemical reagents, it has a powerful attraction for certain salts held in solution and will absorb them completely. This power of absorption is especially marked towards salts of vanadium, these being completely separated from solutions containing only one part of the salt in a trillion.

Besides cellulose itself, there are a number of derived substances which are known as *compound celluloses*. These are classified into three general groups:

(a) *Pectocelluloses*, related to pectin compounds of vegetable tissues; represented among the fibres by raw flax; resolved by hydrolysis with alkalis into pectic acid and cellulose.

(b) *Lignocelluloses*, forming the main constituent of woody tissue and represented among the fibres by jute; resolved by chlorination into chlorinated derivatives of aromatic compounds soluble in alkalis and cellulose.

(c) *Adipocelluloses*, forming the epidermis or cuticular tissue

of fibres, leaves, etc.; resolved by oxidation with nitric acid into derivatives similar to those of the oxidation of fats and cellulose.

Frémy groups the various celluloses and their derived bodies in the following manner, which is based on a chemical classification: (a) *celluloses*, including normal cellulose, paracellulose, and metacellulose; (b) *vasculose* (identical with lignocellulose); (c) *cutose*; (d) *pectose*.

3. Chemical Reactions of Cotton.—Cotton itself presents the same general reactions and chemical properties as cellulose. It is capable of standing rather high temperatures without decomposition or alteration; though it appears that when cotton is subjected to a temperature of 160° C., whether moist or dry heat, a dehydration of the cellulose takes place, accompanied by a structural disintegration of the fibre. This fact has an important bearing on the singeing, calendering, and other finishing processes where high temperatures are used. At 250° C. cotton begins to turn brown; and when ignited in the air it burns freely, emitting an odor faintly suggesting acrolein, but without the characteristic empyreumatic odor of burning animal fibres. When subjected to dry distillation cotton is decomposed into methane, ethane, water, methyl alcohol, acetone, acetic acid, carbon dioxide, pyrocatechol, etc. Though unaltered and insoluble in boiling water, when heated with water under pressure to 200° C. it is dissolved with complete decomposition.

Like cellulose itself, cotton is dissolved by Schweitzer's reagent, though under ordinary conditions its solution is a rather slow process. In order to dissolve cotton most effectively in ammoniacal copper oxide, it is recommended to treat the raw cotton with a strong solution of caustic soda until the fibres swell up and become translucent; squeeze out the excess of liquid, and wash the cotton with strong ammonia water; then treat with the solution of ammoniacal copper oxide and the cotton will be found to dissolve quite rapidly. This solution may furthermore be filtered and diluted with water. The use of this solution for the production of lustra-cellulose filaments has received some degree of commercial application (see Pauly silk). This reaction is also utilized in the production of the so-called *Willesden canvas*; the

cotton fabric is passed through a solution of ammoniacal copper oxide, whereby the surface becomes coated with a film of partially dissolved gelatinized cellulose containing a considerable amount of copper oxide. On subsequent hot pressing this film is fixed on the surface of the material as a substantial coating, which is said to make the canvas water-proof and render it unaffected by mildew and insects.

Concentrated solutions of zinc chloride are capable of dissolving cotton, but only after a prolonged digestion at about 100°C ., though by first treating the cotton with caustic alkali the solution takes place in the cold. The product so obtained has received several industrial applications; *vulcanized fibre* is prepared by dissolving paper in a concentrated solution of zinc chloride, and the resulting gelatinous mass is manufactured into various articles, such as blocks, sheets, etc. The chief difficulty encountered is the subsequent removal of the zinc salt, which necessitates a very lengthy process of washing. The material may be rendered water-proof by a further process of nitration.* The solution has also been suggested for use as a thickening agent in calico-printing. Its use for the production of lustra-cellulose or artificial silk and incandescent lamp filaments has also been attempted.

With mineral acids cotton exhibits practically the same general reactions as pure cellulose. Concentrated sulphuric acid produces amyloid in the manner already mentioned, and this fact is utilized in the preparation of what is known as *vegetable parchment*. Unsized paper is rapidly passed through concentrated sulphuric acid, then thoroughly washed and dried. The effect of this treatment is to cause the formation on the surface of the paper of a layer of gelatinous amyloid, which on subsequent pressing and drying gives a tough membranous surface to the paper resembling true parchment. This renders the paper grease-proof and water-proof, and increases its tensile strength considerably. *Artificial horse-hair* has been prepared in a similar manner from certain Mexican grasses. These latter are steeped for a short time in concentrated sulphuric acid, and become

* Hofmann, Handb. d. Papierfab., p. 1703.

parchmentized thereby, so that on being subsequently washed and combed they assume an appearance very much resembling horse-hair, and are said to possess even greater elasticity than horse-hair itself. In place of strong sulphuric acid a solution of zinc chloride may be used with similar results. Amyloid appears also to be a product of natural plant growth, as its presence has been detected in the walls of vegetable cells; it may be recognized by giving a blue color with iodine.

Very dilute solutions of sulphuric acid, especially in the cold, have no appreciable action on cotton. But if the fibre is impregnated with such a solution and then allowed to dry it becomes rapidly tendered; this is owing to the gradual concentration of the acid in the fibre on drying. Elevated temperatures also cause the dilute acid to attack the fibre much more quickly and severely than otherwise.

In all dyeing and bleaching operations where the use of acid may be required the above facts should always be borne in mind; the temperature of the acid baths should not be above 70° F., and the acid strength should not be more than 2 per cent. Where higher temperatures are necessary organic acids should be substituted for mineral acids wherever possible. Acetic acid, for instance, is often used. Whenever cotton is treated with acid solutions or with salts of an acid nature or which are liable to decompose with liberation of acid, all of the acid should be removed from the fibre or properly neutralized before drying, else the material will be tendered and probably ruined. The action of dilute acid on cotton is probably an hydrolysis of the cellulose molecule, with the formation of hydroxycellulose, causing a structural disorganization of the fibre to take place. Hydrochloric acid has an effect similar to sulphuric acid, and the same remarks concerning the use of this latter acid in connection with cotton also hold true for the former. Strong nitric acid has a somewhat different effect;* it completely decomposes cotton, in

* The action of nitric acid on cotton fabrics appears to be a peculiar one. The following observations in this respect have been recorded by Knecht: Bleached calico steeped for fifteen minutes in pure nitric acid at 80° Tw., washed, and dried, showed a considerable contraction, amounting to about 24 per cent.; the tensile

common with other forms of cellulose, oxidizing it to oxalic acid. When boiled with moderately concentrated nitric acid cotton is converted into *oxycellulose*, a structureless, friable substance possessing a great affinity for basic dyestuffs. When mixed with concentrated sulphuric acid, however, the action of nitric acid is totally different, the cellulose being converted into a nitro-derivative, though the physical appearance of the fibre is not appreciably altered. The exact nature of the nitrated compound will depend on the conditions of treatment. Several nitrocelluloses are known and possess commercial importance; they are classified under the general name of *pyroxylics*. Gun-cotton, a hexanitrocellulose, is the most highly nitrated product, and is used as a basis of many explosives. Soluble pyroxylin is a trinitrocellulose; its solution in a mixture of alcohol and ether is called *collodion* and is employed in surgery and photography. Another derivative, supposed to be a tetranitrocellulose, is also soluble in ether-alcohol, and its solution has been utilized for the production of lustra-cellulose filaments. By dissolving nitrocellulose in molten camphor a substance known as *celluloid* is formed.

The action of hydrofluoric acid on cotton and other vegetable fibres appears to be a peculiar one; a transparent, tough, flexible water-proof material being obtained. The product does not appear to resemble parchment obtained by the action of sulphuric acid. It is used as an insulating material and for making the carbon filaments of incandescent electric lamps.

Organic acids in solution, even when moderately concentrated,

strength also increased 78 per cent. Unbleached yarn, treated in the same manner, also showed a considerable increase of tensile strength, and a proportional contraction in length. Weaker acids did not show these results, the fibre being tendered instead of being strengthened. Analysis proved that 7.7 per cent. of nitrogen was present, showing that about two molecules of the acid had combined with the cotton. The shrinkage, gain in strength, microscopical appearance, etc., of the treated material, all go to show that in addition to the nitration a mercerizing effect has been produced. This appears in the fact that the material exhibits a strongly increased affinity for many dyestuffs, especially the direct cotton colors and some of the acid dyes; while by reason of its not showing any increased affinity for the basic colors there is proof that oxycellulose has not been produced.

do not appear to have any injurious action on cotton. The non-volatile acids, however, such as oxalic, tartaric, and citric acids, when allowed to dry into the fibre, act much in the same manner as mineral acids, especially at elevated temperatures.* Acetic acid, however, being volatile, exerts no destructive action; hence this latter acid is particularly suitable for use in the dyeing and printing of cotton goods, where the use of an acid is requisite.†

Tannic acid, unlike other acids, exhibits quite an affinity for cotton, the latter being capable of absorbing as much as 7 to 10 per cent. of its weight of tannic acid from an aqueous solution. Advantage is taken of this fact in the mordanting of cotton with tannic acid and tannins for the dyeing and printing of basic colors. Cotton exhibits a similar attraction for tungstic acid; the expense of this latter compound, however, precludes its adoption as a mordanting agent.

Though acids, in general, have such an injurious action on cotton, alkalies, on the other hand, are harmless under ordinary conditions. Dilute solutions of either the carbonated or caustic alkalies, even at a boiling temperature, if air is excluded, have no injurious effect on cotton. In the presence of air alkaline solutions cause an hydrolysis of the cellulose in a manner similar to acids, with the result that the fibre is seriously weakened. This action of alkalies in the presence of air is an important one to bear in mind in the operations of bleaching, dyeing, or mercerizing which will be subsequently studied. Boiling solu-

* The destructive action of these acids on the cotton fibre is, perhaps, not so much of a chemical nature as mechanical, it being caused by the acids crystallizing within the fibre and thus breaking the cell-wall. A dry heat, for instance, in connection with these acids is much more injurious than a moist heat, a fact which is of much importance in the drying of cotton prints, where the above-mentioned acids may have been used.

† Oxalic acid appears to have a peculiar effect on cotton; it has been noticed that if a piece of cotton cloth be printed with a thickened solution of oxalic acid, dried, and hung in a cool place for about twelve hours, and then well washed, the printed parts exhibit a direct affinity towards the basic dyes. The cotton so treated does not become tender or otherwise changed. Towards substantive dyes it exhibits considerably less attraction than ordinary cotton, while with alizarin dyes it is partially reactive. Tartaric and citric acids do not produce the same effect, nor does the neutral or acid oxalate of potassium.

tions of dilute alkalies dissolve or emulsify the waxy and fatty impurities encrusting the cotton fibre, hence these reagents are largely employed in the scouring of cotton goods.

The action of alkaline solutions at high temperatures (above 100°C.) on cotton appears, however, to be a destructive one. Tauss has shown that if cotton be digested with solutions of caustic soda under pressure, the fibre is attacked and converted into soluble products; the degree of decomposition depending on the pressure and the strength of the alkaline liquor, in accordance with the following table:

Pressure.	Strength of Alkali.	
	3% Na_2O .	8% Na_2O .
	Per Cent Dissolved.	
1 atmosphere.....	12.1	22.0
5 atmospheres.....	15.4	58.0
10 ".....	20.3	59.0

Solutions of ammonia do not act on cotton until quite high temperatures are reached. According to the experiments of L. Vignon, at 200°C. ammonia reacts with cotton cellulose, the result being the evident formation of an amidocellulose compound, the product evincing a greatly increased degree of absorption for dyestuff solutions, especially for the acid coloring-matters, somewhat after the manner of animal fibres.

This action of alkaline solutions on cotton under high pressure has an important bearing on the bleaching of this fibre, where it is subjected to such action by boiling with alkalies in pressure kiers. This phase of the question does not appear to have received much attention from either the practical bleacher or the theoretical chemist, but it would seem to be worthy of some degree of intelligent research on the part of both.

Concentrated solutions of caustic alkalies have a peculiar effect on cotton; the fibre swells up, becomes cylindrical and semi-transparent, while the interior canal is almost entirely obliterated by the swelling of the cell-walls. There is a marked gain

in weight and strength, while the affinity of the cotton for coloring-matters is materially increased. This effect was first noticed by John Mercer in 1844, and the reaction forms the basis of the modern process of *mercerizing*, under which title a more complete and extensive discussion of this reaction will be found. Solutions of sodium sulphide appear to have no immediate tendering action on cotton, even at a boiling temperature. If the sodium sulphide is dried into the fibre after about six weeks the cotton shows a loss in strength of from 10 to 20 per cent. Also, when sodium sulphide is dried in the fibre at 100° C., the tendering amounts to from 10 to 20 per cent. Cotton containing copper sulphide or iron sulphide shows no appreciable amount of tendering. When cotton is impregnated with sulphur and exposed to a damp atmosphere for several weeks its tensile strength is reduced by about one-half. This is perhaps due to the oxidation of the sulphur into sulphurous and sulphuric acids.

If cotton, or other forms of cellulose, be treated with a concentrated solution of caustic soda to which a small amount of carbon disulphide has been added, the fibres swell up, become disintegrated, and finally form a gelatinous mass. This latter is soluble in a large amount of water, producing a very viscous solution, technically known as *viscose*. From this solution hydrocellulose may be precipitated by sulphurous acid gas, as well as by various other reagents. Precipitation also occurs by simply allowing the solution to stand for some time, in which case the hydrocellulose separates out as a jelly-like mass. Viscose has received several commercial applications, among which may be mentioned more especially the use of its solutions for the preparation of lustra-cellulose filaments.

Though cotton does not show nearly the same degree of affinity for acids and alkalies as do the animal fibres, nevertheless it has been shown that cotton does absorb both acids and alkalies from their solutions, even when cold and dilute. The ratio of absorption appears to be 3 molecular parts of acid to 10 molecular parts of caustic alkali. Vignon, by a study of the thermochemical reactions of cotton, has shown that when this fibre is treated with acids or alkalies a liberation of heat takes place, from which

fact it would appear that cotton exhibits in some degree the properties of a very weak acid and a still weaker base.

Strong oxidizing agents, such as chromic acid, permanganates, chlorin, etc., in concentrated solutions, readily attack cotton, converting it into oxycellulose. This substance appears to possess an increased affinity for dyestuffs, but it is of a structureless and brittle nature, hence its formation greatly tenders the fibre. It is said that oxycellulose is indifferent towards the tetrazo dyestuffs; and, in consequence, these may be employed for the purpose of detecting the presence of oxycellulose in cotton materials.

In its action towards various metallic salts cotton is very neutral, thereby differing considerably from both wool and silk. If the salts, however, are present in a very basic condition, cotton is capable of decomposing them and loosely fixing the metallic hydroxide. Many salts, especially those of an acid nature, will tender the cotton fibre, probably due to the liberation and drying in of the acid. Consequently such salts should be avoided or used very carefully with cotton, and any excess should be thoroughly eliminated by subsequent washing before the material dries.

In its behavior towards coloring-matters cotton differs most markedly from the animal fibres. Of the natural dyestuffs, only a few color the cotton fibre without a mordant; with the coal-tar colors, cotton exhibits no affinity for most of the acid or basic dyes, and these can only be applied on a suitable mordant. The substantive colors, however, are readily dyed on cotton, in a direct manner, and since their introduction the methods of cotton dyeing have been practically revolutionized.

Though resistant to the action of moths and insects in general, cotton is liable to undergo fermentation, as is evidenced by the formation of mildew on cotton fabrics stored in damp places. Though this fermentation is often induced by the presence of more or less starchy matter contained in the sizing materials used in finishing the goods, yet pure cellulose itself can also be fermented, and Omeliansky has succeeded in isolating the particular bacillus which destroys cellulose.

There has been much discussion as to whether the various treatments to which cotton is subjected during the process of bleaching has any deleterious effect on the strength of the fibre. In this connection O'Neill gives the following interesting results, made to determine the tensile strength of cotton threads before and after bleaching:

	Average Weight Required to Break a Single Thread.	
	Before Bleaching.	After Bleaching.
No. 1 cloth, weft-threads.	1714 grains	2785 grains
No. 1 " warp-threads.	3140 "	2020 "
No. 2 " "	3407 "	3708 "
No. 2 " "	3512 "	4025 "

It will be noticed that in two cases out of three the warp-threads are stronger than before, and it may be safely concluded that the tensile strength of cotton yarn is not injured by careful though thorough bleaching, and probably it may be strengthened by the wetting and pressure causing a more complete and effective binding of the separate cotton fibres, the twisting together of which makes the yarn stronger.

CHAPTER XII.

MERCERIZED COTTON.

1. **Mercerizing** is a term applied to that process whereby cotton is treated with concentrated caustic alkalies. In its strictest significance, however, it refers most directly to the process of giving cotton a high degree of lustre by subjecting it simultaneously to the chemical action of caustic alkalies and the mechanical action of strong tension sufficient to prevent contraction. The process is named from John Mercer, who first discovered the effect of strong solutions of caustic alkalies on cotton in the year 1844. It was not until the last decade, however, that the process attained any degree of commercial success; but during the last few years it has given practically a new fibre to the textile industry.

Mercerizing, in its essential meaning, relates to the action of certain chemicals on cellulose whereby the latter is changed to a product known as *cellulose hydrate*; though, technically, the term has come to mean the process concerned with the imparting of a silk-like lustre to the fibre. As generally understood, it consists briefly in impregnating cotton yarn or cloth with a rather concentrated cold solution of caustic soda and subsequently washing out the caustic liquor with water, the material being either held in a state of tension during the time it is treated with the caustic alkali in order to prevent contraction, or stretched back to its original length after treatment with the alkali, but previous to washing. In either case, the material must be in a state of tension during the process of washing. There are two separate phases of the mercerizing process represented in the

above operations which must be separately understood in order to comprehend the exact nature of the change which takes place in the appearance of the fibre; the one is the chemical action of the caustic soda, and the other is the mechanical effect brought about by the tension. The action of the caustic alkali is to effect a chemical transformation in the substance of the fibre, a further chemical reaction taking place when this product is treated with water. As already pointed out (p. 145), cellulose has the property of combining with caustic soda to form a product known as alkali-cellulose, $C_{12}H_{20}O_{10} : NaOH$. The formation of this compound does not appear to disintegrate the organic structure of the fibre-cell, provided the proper conditions are maintained. The alkali-cellulose, however, is apparently a rather feebly combined molecular aggregate, and does not exhibit much stability towards reagents in general. It is even decomposed by the action of water, the effect of the latter being to disrupt the bond of molecular union between the alkali and cellulose, with the consequent re-formation of caustic soda and the introduction of water into the cellulose molecule. This latter substance, which may be termed cellulose hydrate, forms the chemical basis of mercerized cotton. The theory that caustic soda effects a true chemical combination with cellulose is somewhat supported by the fact that mercerized cotton undergoes chemical changes to which ordinary cotton is not susceptible. For instance, the former is much more readily dissolved by a solution of ammonio-copper oxide; it is chemically reactive with carbon disulphide with the formation of soluble cellulose thiocarbonates; alkali-cellulose also reacts with benzoyl chloride and acetic anhydride, giving rise to cellulose benzoates and acetates. The nature of the chemical change from ordinary to mercerized cotton, however, is rather ill-defined; it no doubt can be included under that class of reactions which stands somewhat midway between ordinary physical and chemical changes, and is to be particularly observed in connection with those bodies possessing a high degree of molecular complexity, such as various colloidal substances, and the large number of naturally occurring carbohydrates, starches, gums, etc. The fact that there is no evidence of disorganization in the fibre-

cell, as may be observed from its physical properties and microscopic appearance, is a strong argument against true chemical change, which would necessitate a rearrangement in the atomic grouping in the substance of the fibre. This would result in a decomposition of its organized structure, which would at once be manifested in a decrease in the tensile strength, and a gradual breaking down of the fibre itself. But mercerized cotton shows no such change; on the other hand, its tensile strength is considerably increased, and the fibre-cell shows no tendency towards physical decomposition.

When the cotton fibre is immersed in a concentrated solution of caustic soda it undergoes a peculiar physical modification; it appears to absorb the alkali, swelling up to a cylindrical form, so that it presents more the appearance of a hair than a flat ribbon; the fibre also untwists itself and becomes much straighter, at the same time shrinking considerably in length. The internal portion of the fibre acquires a gelatinous appearance, becoming somewhat translucent to light, though it is firm in structure; the external surface of the fibre shows a wrinkled appearance transversely, due to a somewhat unequal distension of the inner part. There is a small degree of lustre on portions of the surface, but, due to the uneven stretching and wrinkling of the external superficies, the smooth lustrous portions are irregular in occurrence and not very extensive in area. The fibre also shows a slight increase in weight. These changes in the physical appearance of the fibre are accompanied by a remarkable increase in the tensile strength, amounting in most cases to as much as 30 to 50 per cent.; the fibre also acquiring a greater power of absorption towards many solutions, most notably those of dyestuffs. The increase in tensile strength is probably due to the fact that mercerizing causes the inner structure of the fibre to become more solidly bound together by a filling up of the interstitial spaces between the molecular components of the cell-wall. In this manner the fibre as a whole is given a greater degree of solidity; the internal strain between the cell elements (which must be quite considerable after the drying out and shrinking of the ripened fibre) is lessened no doubt, and hence adds to the

unified strength of the fibre. From the fact that the fibre shrinks in length in mercerizing, it is probable that the cell elements have contracted transversely on the collapse of the fibre canal, and on being distended again by the action of the caustic alkali these cell elements become shortened longitudinally, and are more tightly packed together. The increased affinity for dye-stuffs exhibited by mercerized cotton is not to be considered a new inherent property of the modified cellulose induced by a change in its chemical composition. It is no doubt a result of the modified physical structure of the fibre itself; that is, when the cell elements have become distended, like a sponge they have a greater power of absorption and retention of liquids than when in a flattened and collapsed condition.

The high lustre imparted to the cotton by mercerizing is brought about by other conditions than the mere action of the caustic alkali.* In the swelling of the cell-walls and consequent contraction of the fibre, the surface remains wrinkled and uneven, due to the unequal strain of expansion. If, however, the ends of the fibre are fixed, and thus prevented from contracting when subjected to the chemical action of the alkali, the swelling of the cell-walls will cause the surface to become smooth and even, and capable of reflecting light with but little scattering of the rays, similar to a polished surface. Another condition which also has much to do with the production of the lustrous appearance is no doubt to be found in the physical modification of the cell elements themselves. When the fibre swells up under the action of the caustic alkali, its substance becomes gelatinous and translucent, and this has a marked effect on the optical properties of the fibre, and enhances the lustre considerably by lessening the proportion of light absorbed.†

* It has been claimed that the mercerizing effect may be obtained without tension by the addition of glucose to the alkaline bath. The addition of other substances, such as ether, aluminium chloride, etc., have been claimed to produce the same result. But it is to be doubted whether a high lustre is obtained by any of these methods.

† Dr. Fränkel has advanced the opinion that the high lustre exhibited by mercerized cotton is mainly due to the fibre having lost its thin cuticle during the process. But this theory is overthrown by the fact that if mercerized cotton

Considerable difference is to be observed in the strength and elasticity of cotton mercerized without tension and that mercerized with tension. Buntrock, in a research on this point, found that cotton yarn mercerized without tension showed an increase of 68 per cent. in its tensile strength,* whereas the same cotton mercerized under tension gave an increase of only 35 per cent. With respect to the elasticity of the yarn, the same chemist ascertained that the untreated cotton employed in his experiments stretched 11 per cent. of its length before breaking; the amount for cotton mercerized without tension was 17 per cent., an increase of 54 per cent.; cotton mercerized under tension showed no increase in elasticity at all, and could only be stretched the original 11 per cent. before breaking. These figures, of course, are not absolute for all varieties of cotton, but will vary within considerable limits, depending upon the character of the raw cotton employed. Attention must also be drawn to the fact that the figures for the tensile strength and elasticity quoted above were obtained by using spun yarn and are not based on the single fibre. Of course it is the strength of the yarn which is desired in practice, but the figure for this is not necessarily that for the fibre itself. In mercerizing yarn or cloth, it must be borne in mind that the fibres shrink considerably, and in doing so become more closely knit together; therefore the increase in tensile strength, as ascertained by Buntrock, represents really the greater coherence of the fibres to one another, rather than an increase in the strength of the individual fibre, because in breaking a yarn spun from a large number of fibres there is little or no actual breaking of the fibres themselves, but only a pulling apart of the latter. The same criticism also applies to a determination of the elasticity. It would, perhaps, be more scientific to determine the breaking

is again subjected to the action of cold strong caustic soda it contracts nearly as much as raw cotton would do, and loses its silky lustre entirely.

* Grosheintz gives the following results of some experiments on the effect of mercerization on the tensile strength of cotton. Unmercerized yarn broke with a load of 356-360 grams; same yarn mercerized in cold aqueous caustic soda (35° B.) broke with 530-570 grams; same yarn mercerized with cold alcoholic caustic soda (10 per cent.) broke with 600-645 grams; same (except that hot alcoholic caustic soda was used) broke with a load of 690-740 grams.

strain and elasticity of the separate fibres rather than that of the yarn or cloth; but it may be assumed, with considerable show of reason, that these figures of Buntrock will represent a fair relation between the strength and elasticity of the individual fibres. The cause of the lesser increase in tensile strength of cotton mercerized under tension as compared with that of the same cotton mercerized without tension is to be attributed to the fact that when the shrinkage of the fibre is prevented by the application of an external force, the cell tissues cannot become as compact as otherwise, and there is also an internal strain induced which lessens the ultimate strength of the fibre. This latter condition also accounts for the lack of any increase in the elasticity of the mercerized fibre; the fibre when mercerized under tension is already in a stretched or strained condition, and can hardly be expected to give the same degree of elasticity as if tension had not been applied.

2. Conditions of Mercerizing.—The proper conditions for carrying into practical operation the mercerizing process are simple and easily realized. Caustic soda is the most suitable and convenient reagent* for bringing about the hydration of the cellulose; and it has been found that a solution of density between 60° and 70° Tw. gives the best results. Caustic soda solutions of less density than 15° Tw. have scarcely any action on cotton; the maximum effect appears to be produced by a concentration of about 60° Tw., though the difference between this and that obtained at 50° Tw. is not very marked, and even at 40° Tw. the mercerizing action of the alkali is quite strong. Other reagents, however, than caustic alkalies, may be employed for the hydrolysis of the cotton. Concentrated mineral acids, such, for instance, as sulphuric acid at a density of 100° to 125° Tw., will bring about the mercerizing effect more or less perfectly; the same is also true of certain metallic salts, most notably the chlorides of zinc, calcium, and tin. Beyond a mere theoretical

* Solutions of caustic potash probably give a somewhat better lustre, and the shrinkage of the fibre is less than with caustic soda. But these small advantages are not sufficient to compensate for the extra expense which would be entailed by the use of caustic potash.

and chemical interest, however, mercerizing by means of such reagents has no practical value.* The addition of various chemicals, however, has been made to the caustic alkali solution with beneficial results. It has been observed, for instance, that the addition of zinc oxide has a very marked effect, and probably is of considerable value in the practical working of the process. The addition of glycerin, though perhaps of some benefit in assisting in the even and thorough penetration of the liquor into the fibre, can hardly be said to appreciably modify the general operation of the alkali.† Previous treatment with Turkey-red oil is also of benefit for the same reason; this is also true of such substances as sodium silicate, sodium aluminate, and soap.

The temperature at which the reaction is carried out should not be higher than the usual atmospheric degree; in fact, it has been recommended to lower the temperature of the caustic soda solution by the addition of ice, but this procedure does not appear to add anything of material advantage. At elevated temperatures caustic soda appears to exert a destructive effect on cotton, probably due to the formation of oxycellulose through hydrolysis and subsequent oxidation. Beyond a certain temperature the mercerizing effect rapidly diminishes, and at the boil it is scarcely appreciable.‡ The best results appear to be obtained when the

* The use of sulphide of sodium or potassium instead of caustic alkali has been proposed; but the process yields very uncertain results. It is claimed that by adding ether to the caustic soda solution good mercerization can be obtained with but little contraction of the fibre, but as this process requires fifty parts of ether to twenty parts of caustic soda solution, the expense renders it ridiculously impracticable. It is said that the addition of carbon bisulphide to the bath of caustic soda very materially increases the lustre; this causes a disintegration of the fibre, however, through the formation of viscose (see p. 153); hence the treatment should be very brief, otherwise the cotton will be seriously tendered. The mercerized fibre at first is as stiff as horse-hair, but this effect can be removed by repeated washing. The sulphur can be removed from the cotton by washing in a solution of sal-ammoniac, and this should be done before the material is treated with an acid bath, as the latter would cause a precipitation of sulphur on the fibre and so spoil the lustre.

† In the practical manipulation of the mercerizing process it has been found that the impregnation with caustic liquor is greatly facilitated by the addition of 5 per cent. of alcohol on the weight of the caustic soda.

‡ Beltzer, however, claims that caustic soda solutions of 65° Tw. gave the same results in mercerizing at 90° C. as at 15° C., but the cotton mercerized at

temperature is maintained at 20° C., or lower. Above this point the contraction of the fibre (which may be taken as a measure of the degree of mercerization) grows less and less with rise of temperature.

The mercerizing action of caustic soda is rather a rapid one, as it requires only a few minutes for its completion; in fact, it appears to take place simultaneously with the impregnation of the fibre by the liquid. In ten minutes mercerization is practically complete, and lengthening of the time does not increase the mercerizing effect; in fact, too long a contact of the cotton with the caustic alkali is to be avoided, especially if the impregnated fibre is exposed to the air, as there is danger of a breaking down of the cellular structure and a consequent deterioration in the strength of the fibre. The time of immersion also appears to be independent of both the temperature and the concentration of the alkali.

There are two ways in which the tension may be applied in mercerizing: (a) The material may be held in a state of tension during the time of its treatment with the caustic alkali, and until the alkali has been washed out, in which case the tension should be so maintained that the material cannot shrink; (b) the tension may be applied after the material has been treated with the caustic alkali, but before the latter is washed out, in which case sufficient tension should be exerted to stretch the material back to its original length. If the tension is not applied until after the alkali has been removed from the fibre, no lustring effect is produced; it is absolutely essential that the stretching should take place while the fibre is in the form of an alkali-cellulose, and before it has been converted by treatment with water into hydrated cellulose.

According to the experiments of Herbig, the stretching force necessary to keep the cotton in its original length during mercerization is only from a quarter to a third of that necessary, to do

the higher temperature was much more transparent than the other. The lustre, however, was in no wise inferior. If the mercerization be conducted at 90° C. it is necessary to keep the cotton entirely immersed, to guard it from contact with the air, otherwise it will become seriously weakened.

the stretching after mercerization; but there appears to be no appreciable difference in the lustre obtained. It would appear, however, that stretching beyond a certain point ceases to increase the lustre, and to obtain the maximum lustring effect it is not necessary to stretch the cotton back to its original length. Herbig concluded that stretching during mercerization is disadvantageous, and it is best to mercerize the yarn loose, wring it, and only stretch while rinsing, as the required stretching force is then quite small. The best time for stretching, then, is during the conversion of the soda-cellulose into the hydrocellulose. If the stretching does not take place until after rinsing, almost twice the force is necessary to restore the yarn to its original length, as when in contact with the lye, and the lustre is decidedly inferior. The stretching force also appears to depend on the twist, being greater in proportion as the twist is harder.*

* Herbig gives a summary of his experimental results as follows:

1. Loose yarn mercerized without any stretching, whether long- or short-stapled, and whether with or without a hard twist, has less lustre than unmercerized yarn. But even with a very slight tension the lustre is greater.
2. Both with long- and short-stapled cotton the lustre only becomes marked when the stretching force is sufficient to bring the yarn back to its original length.
3. Stretching beyond the original length does not give any increase in lustre.
4. Considerable difference is observable in the stretching force needed between loose mercerization followed by stretching in the lye, and keeping the cotton at its original length during mercerization, as in the latter case only one-third to one-quarter of the force is necessary to produce the silky lustre.
5. The stretching of the yarn requires only a small force when mercerized loose and if applied when rinsing is actually in progress; for the best time for stretching is during the conversion of the soda-cellulose into hydrocellulose.
6. When rinsing is over, twice as much force is needed to restore the original length as is required for yarn still in contact with the lye; and yarns so treated contract somewhat on drying, and exhibit an inferior lustre.
7. The stretching force necessary in mercerizing yarn varies with the twist, and in general is greater in proportion as the twist is harder.
8. The production of the silky lustre does not depend primarily on the amount of force employed in stretching, as soft yarn with only a small amount of twist can be lusted.
9. The production of the silky lustre is independent of the cotton being long- or short-stapled, as short-stapled American cotton with even a loose twist can be given a silky lustre.
10. The production of a high degree of lustre depends to a considerable extent on the fineness of the fibre, and its natural lustre. This is apparent in mercerizing sea island and Egyptian cotton.

By the washing of the material after steeping in caustic alkali, a twofold object is gained. In the first place, the action of the water on the alkali-cellulose is to effect a chemical transformation into cellulose hydrate, and this action is as really essential to mercerizing as the action of the caustic soda itself. In the second place, the washing is conducted for the purpose of removing all excess of caustic alkali from the material.* Caustic soda is held quite tenaciously by cotton, and it requires a very thorough and long-continued washing to remove the last traces of this compound. In order to shorten the period required for washing, it is customary to give the cotton first a rinsing in fresh water, after which the tension may be relieved, and then to wash with acidulated water, using acetic acid for this purpose.† On drying the material without further washing, it will be found that the acetic acid has imparted to the cotton a certain degree of "scoop" somewhat after the nature of silk, without in any manner tendering the fibre. If other acids, and especially mineral acids, are employed for washing, a subsequent rinsing with fresh water and soaping is necessary for the purpose of neutralizing all of the acid, which would otherwise seriously tender the goods on drying unless the amount of acid employed is so accurately adjusted as not to leave any free acid in the fibre.

The character of the fibre employed has a considerable influence on the success of the mercerizing process. From the very nature of the fact that a considerable degree of tension must be applied to the fibre during the process in order to obtain the desired lustre, it would be natural to expect that the longer the staple of the fibre the more readily would it lend itself to the requirements of the operation. And such, indeed, is found to be the case; the long-stapled sea-island ‡ and Egyptian varieties

* When mercerized cotton is rinsed with ammonia instead of water it retains its gelatinous, parchment-like consistency throughout the rinsing, and can be stretched to its original length without breaking. If the cotton is then rinsed with water while still stretched, the fibre regains its original appearance, and acquires a lustre as good as that obtained in the usual way.

† Sulphuric acid is much used in the washing. The acid employed is of $\frac{1}{2}^{\circ}$ B. strength, and at a temperature of 50° C.

‡ The preparation by combing of cotton for mercerization has a considerable

of cotton are those especially adapted for use in the preparation of mercerized cotton, while the shorter-stapled varieties are but little employed for this purpose, as the lustre obtained with them is by no means as pronounced.* The quality of being mercerized, however, is not an inherent property of any special variety of cotton, as was formerly supposed to be the case; any variety of cotton is capable of mercerization, the only essential being that the fibre shall be maintained in a state of tension. In order that this condition be realized with short-stapled fibres, the yarn operated upon must be tightly twisted in order to present sufficient cohesion among the individual fibres to allow of the high tension required; this, on the other hand, prevents an even and thorough penetration of the caustic alkali into the substance of the fibre, so that, on the whole, the results obtained with short-stapled fibres are not at all comparable with the long-stapled varieties.† By later improvements in the manner of applying

influence on the subsequent lustre of the yarn. Sea-island cotton possesses a rather silky fibre to begin with, and this is made more adaptable to the production of a high lustre by combing, in which operation the fibres are arranged parallel, and still further by gassing, which burns off the minute outer hairs. Yarns possessing considerable lustre were made in this manner with fine counts of sea-island cotton long before the discovery of lustring by mercerization, and it was always recognized that the parallelism of the fibres so obtained by combing (and sometimes a second combing) was a great factor in the production of a silky and lustrous yarn.

* Fabrics of vegetable fibres (cotton or linen) may also be mercerized in patterns by printing on certain compounds capable of resisting the action of the caustic soda in the subsequent mercerizing process. Resists suitable for this purpose are, in the first place, organic compounds which readily coagulate, such as albumin and casein; and secondly, such salts, acids, or oxides which may act by neutralizing the caustic alkali, or from which a hydrate may be precipitated on the fabric by its action. Such compounds, for instance, as the salts of aluminium or zinc, organic acids, and the oxides of zinc, aluminium, or chromium are quite suitable. Very beautiful effects are said to be obtainable by this process.

† Boucart gives the following reasons why only long-stapled cotton, and that only in particular counts, gives good results on mercerization. A simple thread consists of a sort of twisted wick composed of nearly parallel fibres. The twist depends, as regards the angles it makes with the length of the thread, both upon the kind of cotton and upon the count of the yarn. Of the two sorts of simple yarns, warp-yarns have more cohesion among their elements than tensile strength, while the reverse is the case with weft-yarns. The result is that under gradually

the tension, however, it would seem that, by realizing the proper mechanical conditions, even cotton of comparatively short staple will be capable of being mercerized in a more successful manner than heretofore.*

3. Properties of Mercerized Cotton.—Outside of its high lustre and somewhat increased tensile strength, mercerized cotton exhibits but few apparent differences from the ordinary fibre. Towards dyestuffs and mordants it is rather more reactive, and

increasing tension weft-fibres slide past one another without breaking, but warp-fibres break before any such occurrence takes place. The degree of twist also depends on the mean staple, and the angle between the thread and the axis at any point is proportional to the length of the thread. The degree of twist which is required to make the cohesion exceed the tensile strength depends naturally on the strength of the fibre. The mercerizing process tends to shorten each individual fibre, and this shortening is resisted by tension in the direction parallel to the axis of the thread. Hence the greater the angle the thread makes with that axis the less is the effect of the tension, and if any portion of the fibre is at right angles to the axis it is not affected by the tension at all. Hence a simple warp thread can only receive a medium amount of gloss from mercerization, and the less the greater the twist. Slightly twisted threads must give the best lustre, but if the cohesion of the fibres is less than the contractile force exerted by the lye, the fibres slip past each other and no lustre is produced. But if the weft-threads are fixed, as in piece goods, they take a better lustre than the warp, although the latter is usually made of better cotton. Short-stapled cotton lustres badly because it must be more tightly twisted. The best lustre of all is obtained with twofold twist, in which the outer fibres lie parallel to the axis, and the yarn should be well singed to remove projecting threads.

* The process of mercerizing has been subject of late to a great number of patents, especially by Thomas and Prevost of Germany. This has resulted in considerable litigation in many countries. As far as the actual chemical process itself is concerned, however, there does not appear to have been any material advance beyond the facts first discovered by Mercer and patented by him in 1850; with regard to the element of carrying out the process under tension, it may be said that this was first described and patented by Arthur Lowe in 1890, and this included the application of tension either during or after the treatment with caustic alkali. Lowe's object in stretching the material, however, was primarily to prevent the loss encountered by the shrinkage of the goods, though he does also make a specific statement that the cotton acquires an increased lustre and finish by the process. The only novelty put forward by Thomas and Prevost was the use of a particular kind of cotton, that is, long-stapled varieties; but as both Mercer's and Lowe's patents claim the use of all varieties of cotton, it is difficult to see on what ground Thomas and Prevost can substantiate their claim for a patent. Patents covering the process of mercerizing appear to be without foundation; though for machinery and appliances for carrying out the same such patents may be perfectly legitimate.

consequently will dye deeper shades with the same amount of dyestuff than ordinary cotton; this property is rather to be ascribed to the increased absorptivity of the fibre than as the result of any chemical modification of the cellulose composing it; it is also independent of the method of mercerizing, that is, whether accompanied by tension or not.

Microscopically the mercerized cotton fibre exhibits a considerable difference from that of ordinary cotton. Whereas the latter when viewed under the microscope appears as a twisted flat band with thickened edges, and in cross-section like a collapsed tube, mercerized cotton appears as a smooth rounded cylindrical fibre, the cross-section of which is more or less circular. It rarely happens that a fibre absolutely loses all of its twist, though the degree of mercerization may be measured by the freedom of the fibre from irregularities and twists. Under ordinary conditions when the cotton is mercerized in a state of tension, it will also be found that many fibres will remain in their original form, or unmercerized, whereas others will be mercerized only in portions of their length. The microscopical examination of mercerized cotton is important in determining just how perfectly the process has been carried out, which may be judged by the relative number of unmercerized or partially mercerized fibres which may be present.

Cotton may be mercerized either in the form of yarn or of cloth, and it is principally done in the unbleached condition. There has been some dispute as to which is best: to mercerize first and bleach, or to bleach first and then mercerize; experience, however, appears to favor the first method. In the bleaching operations, which usually involve a rather severe treatment of the cotton first with moderately strong alkalies and subsequently with solutions of bleaching powder, the fibre suffers more or less chemical alteration so that in the mercerizing process it can no longer enter into chemical union with the caustic soda employed; and hence true mercerization is not effected. Although cotton should be thoroughly scoured ("boiled out") before being mercerized, it is best not to use alkalies for the purpose, but to employ Turkey-red oil (or other suitable sulphated oil) or soap. If

bleaching is carefully conducted after mercerizing, the injury to the lustre of the fibre is very slight. Mercerized cotton does not require a prolonged boiling in alkalies previous to the operation of bleaching as with ordinary cotton. To obtain the best conditions for high lustre yarn should be well "gassed" (singled) before mercerizing, as otherwise the external, hairy fibres remain loose and cannot be subjected to tension. As a result these fibres shrink, and, remaining without lustre themselves, hide to a certain extent the lustred surface of the yarn. Moreover, caustic soda has a felting action on these free filaments, and felting is especially harmful to lustre.

In mercerizing cloth the action taking place between the sizing materials (always present to a greater or lesser degree in cotton cloth) and the caustic alkali is sufficient at times to raise the temperature considerably, which may result in a deficient lustre. In such cases recourse must be had to artificial cooling by addition of ice or a current of cold water in order to prevent an undue rise in temperature.

When mercerized cotton is to be bleached, it is best, after the first rinsing, to remove the major portion of the caustic soda and arrest the mercerization, not to rinse again in acidulated water, as would ordinarily be done if the material were not to be immediately bleached. The small amount of caustic soda which still remains in the cotton acts in a beneficial manner in bleaching.

A silky lustre resembling that produced by mercerization can be given to cotton cloth by means of what is known as a calender finish. This is accomplished by passing the cloth between rollers under heavy pressure, one of the rollers being engraved with obliquely set lines ruled from 125 to 600 to the inch. The effect is to produce a large number of parallel, flat surfaces on the cloth, which causes it to acquire a high lustre. By conducting the operation with hot rollers quite a permanent finish can be produced which closely approximates mercerized cotton. Cloth so finished, however, loses its lustre in a large degree on washing. The method is chiefly known as the "Schreiner process."

CHAPTER XIII.

ARTIFICIAL SILKS; LUSTRA-CELLULOSE.

OWING to the high price and value of silk as a textile fibre, there have been numerous attempts made to produce an artificial filament resembling it in properties. Several of these processes have been attended with a considerable degree of success, and at the present time artificial silk has become a commercial article, and is used in considerable quantity by the textile trade. The varieties of these silks divide themselves into the following classes:

(1) Pyroxylin silks, made from a solution of guncotton in a mixture of alcohol and ether.

(2) Fibres made from a solution of cellulose in ammoniacal copper oxide or chloride of zinc.

(3) Viscose silk, made from a solution of cellulose thiocarbonate.

(4) Gelatin silk, made from filaments of gelatin rendered insoluble by treatment with formaldehyde.

With the exception of the last class, all of these so-called silks are filaments of cellulose, resolidified from various forms of solutions, hence it has been proposed to give these fibres the general name of *lustra-cellulose*, as one more descriptive of their true nature.

The large majority of the lustra-cellulose used in trade at the present time falls under the first class of pyroxylin silks. This represents the oldest and most successful method employed for the manufacture of this interesting fibre; and there are three chief processes by which the silk is made, known by the names of the respective inventors: Chardonnet, du Vivier, and Lehner. All of these processes use a solution of nitrocellulose as a base,

and employ the same general mechanical idea to produce the filament or fibre, the principle being to force a solution of nitrocellulose through a fine capillary tube, coagulate the thin stream of solution thus obtained, and finally denitrate and reel the thread or filament so obtained. As described on p. 150, cellulose, on treatment with nitric acid, can be made to yield a series of nitrocelluloses, the exact compound obtained being dependent upon the conditions of treatment.

Chardonnet silk is prepared from octonitrocellulose, dissolved in a mixture of alcohol and ether. The solution is coagulated by passage through water, and is subsequently denitrated* by a treatment with dilute nitric acid, chloride of iron, and ammonium phosphate. It forms a glossy, flexible fibre, possessing the peculiar "feel" and "scroop" of true silk.

The basis of du Vivier's silk is a solution of trinitrocellulose in glacial acetic acid. In practice, this is mixed with a solution of gutta-percha in carbon disulphide, and one of isinglass in glacial acetic acid. Small quantities of glycerin and castor-oil are added, and the mixture is drawn through the spinning-tubes into water, where it becomes coagulated. The thread which is so formed is treated successively with soda, albumin, mercuric chloride, and carbon dioxide. Du Vivier's silk is hard, and very white and glossy.

Lehner employs a solution of nitrocellulose in ether and methyl alcohol, to which he adds a solution of natural silk in glacial acetic acid. The thread is coagulated by passage through a mixture of turpentine, chloroform, and juniper-oil, and is afterwards treated with a solution of sodium acetate.†

* When first prepared, pyroxylin silks were very inflammable, which led to their being regarded with disfavor. The processes of denitration, however, have now rendered them even less inflammable than ordinary cotton. *Antiphlogin* is the trade-name of a mixture for the purpose of overcoming the inflammable nature of artificial silk. It consists of boric acid, phosphate of ammonia, and acetic acid. Pyroxylin steeped in this solution is said to be incombustible.

† The manufacture of artificial silk has of late years become an enterprise of commercial importance. There are factories producing pyroxylin silk at Besançon (France), Spreitenbach and Zurich (Switzerland), Wobton (England), and Elberfeld (Germany). The fibres are formed by forcing the ether-alcohol solution of pyroxylin through glass capillary tubes and winding them on

The chief drawback to the rapid progress of collodion silk is its behavior with water.* When wetted the fibre loses its original strength to such a degree that it must be handled with great care. Soap solutions and free dilute acids have no injurious effect, but free alkalies rapidly disintegrate the fibre and finally dissolve it completely. The material is difficult to dye on account of the weakening action of water, and the operation must be carried out with great care. The dyeing is accomplished without the addition of either soap or acid to the bath. The basic coloring-matters and some of the direct cotton colors appear to be the best dyestuffs to employ.

Besides the three processes already given of obtaining collodion silk, there are other methods for the manufacture of this artificial product. Langhaus employs as a raw material a preparation from cellulose and sulphuric acid. Cadarat uses nitro-cellulose, dissolving it in a very complex mixture of glacial acetic acid, ether, acetone, alcohol, toluol, camphor, and castor-oil. This forms a plastic mass which is treated with some proteid substance, such as gelatin or albumin dissolved in glacial acetic acid. After spinning, the fibres are treated with tannin in order to render them elastic.

Hoepfner † has prepared porous acid-proof fabrics to be employed for filtering purposes in electrolytic work by using cotton yarn which has been nitrated. The latter can be woven along with asbestos, glass, or other mineral fibres in the making of the fabric.

frames. As the solution is very viscous, it requires a pressure of 45 atmospheres to discharge it through the capillary openings. It was formerly the custom to carry out the dyeing of pyroxylin silk in the pulp, but this proved to be impracticable, and at present it is chiefly dyed in the form of yarn. The proportion between the price of natural and artificial silk is approximately as follows: Natural silk, \$10 per kilo; pyroxylin silk, \$4.75 per kilo; gelatin silk (vanduara), \$2.40 per kilo.

* Artificial silk appears incapable of withstanding high temperatures, being rapidly charred and destroyed when heated to 150° C. A method for the analysis of materials containing this substance has been proposed, using this fact as a basis. The material under examination is heated for ten minutes at 200° C. Cotton, wool, and silk are not materially injured, but artificial silk is completely carbonized, and on rubbing will be reduced to a dust.

† *Färber Zeit.*, 1897, No. 5.

If nitrated cotton be examined under the microscope, a considerable alteration in its appearance will be observed. The fibres are much thicker in the wall, and are consequently stiffer than those of ordinary cotton. The lumen has either vanished entirely or become very much contracted, and this appears to be due to the swelling of the cell-walls. In the walls of the fibre there will also be noticed numerous fractures or cracks which often assume a spiral shape. The nitration has evidently rendered the fibre much more brittle and has decreased its elasticity.

Solutions of nitrocellulose have been employed for a number of purposes, such as the production of films for photographic use, the manufacture of lacquers, etc. The author has also successfully utilized such a preparation for the waterproofing of paper and other materials. It also forms an excellent waterproof sizing and stiffening agent for all manner of textile fabrics and hats.

As the solutions of nitrocellulose possess great viscosity, it is difficult to prepare a very concentrated solution. The addition of formaldehyde or benzol, however, to the ordinary solvents, will increase the dissolving capacity considerably, and also give a more mobile solution. Epichlor- and dichlorhydrins also act as excellent solvents for nitrocellulose, being capable of dissolving it in any proportion.

Vanduara silk * is a thread of gelatin, and consequently differs from the other artificial silks in that it consists of animal tissue and not vegetable. Due to this circumstance it has more analogy chemically to true silk than the various cellulose silks. The manufacture of vanduara silk is conducted by pressing an aqueous solution of gelatin through a fine capillary tube; the thread so produced is carried on an endless band through a drying-chamber. The soft gelatin thread, of course, flattens out considerably during this operation, hence the silk eventually forms a flat, ribbon-like fibre. After drying and properly reeling, the fibre is treated with vapor of formaldehyde, which causes the gelatin to become insoluble in water. By varying the pressure on the

* *Vanduara silk* is an English invention, the patentee being Adam Millar. The silk has never appeared on the market as a commercial commodity, and the process does not seem to have met with any marked degree of success.

gelatin solution, whereby it is forced through the capillary tube, the thickness of the fibre may be increased or diminished. The same result may be attained by varying the speed of the endless band which carries the thread after coming from the capillary tube. The silk may be dyed either in the ordinary way in skein form after reeling, or the gelatin solution may be colored before the thread is drawn out. The fibre is very lustrous, and if the filaments are drawn fine enough, the silk is soft and pliable.

Hassac* gives a comparison of several makes of artificial silk. Chardonnet's and Lehner's silks are very similar in appearance; they are more lustrous than real silk, but are stiffer, and do not possess the characteristic feel. Cellulose silk made by Pauly's ammoniacal copper oxide process is similar to the former in appearance, but its lustre is even better, and it has the characteristic feel of true silk. Lehner's silk under the microscope is characterized by deep longitudinal grooves and small air-bubbles; its cross-section is highly irregular. Pauly's silk shows fine longitudinal grooves, and minute transverse lines in the centre of the fibres; its cross-section is regular, approaching a circle or ellipse. Hammel's gelatin silk is almost circular in outline, and is free from grooves and bubbles; in polarized light it is singly refracting, while the others are doubly so.

As the collodion silks always contain some nitro-compound, they give a blue color with diphenylamin and sulphuric acid. Water causes all the artificial silks to swell, while alcohol or glycerin contracts them. In strong sulphuric acid the collodion silks swell rapidly and dissolve; Pauly's cellulose silk gradually becomes thinner and dissolves; gelatin silk only dissolves on strong heating. Chromic acid dissolves all artificial silks in the cold; real silk dissolves but slowly; while cotton and other vegetable fibres are unaffected. Caustic potash does not dissolve the collodion or cellulose silks, but both the gelatin silk and real silk are soluble on boiling. Schweitzer's reagent dissolves collodion and cellulose silks; whereas gelatin silk is insoluble, but stains the liquid a bright violet. Alkaline copper glycerin solution at 80° C. dissolves real silk immediately. Tussah and gelatin

* *Chem. Zeit.*, 1900, 235, 267, 297.

silks dissolve when boiled for one minute; the other silks are not affected. Iodin solution colors artificial silks an intense red, which changes to a transient pale blue on washing with water in the case of collodion silks, though cellulose silk does not show this blue. Iodin and sulphuric acid stain true silk yellow, gelatin silk brown, collodion and cellulose silks blue.

Silk.	Moisture.		Sp. Gr.	Fibres to Sq. Mm.		Tens. Strength, Kilo. per Sq. Mm.		Extension, Per Ct.
	Air-dry, Per Ct.	Saturated, Per Ct.		Wet.	Dry.	Wet.	Dry.	
Real silk.	8.71	20.11	1.36	9710	9710	37.0	37.0	21.6
Chardonnet.	11.11	27.46	1.52	640	1135	2.2	12.0	8.0
“ (Walston).	11.32	28.94	1.53	683	1620	1.0	22.3	7.9
Lehner.	10.45	26.45	1.51	413	1180	1.5	16.9	7.5
Pauly.	9.20	23.08	1.50	742	1550	3.2	19.1	12.5
Gelatin.	13.98	45.56	1.37	265	945	0.0	6.6	3.8

Strehlenert and Westergren give the following figures for the tensile strengths of various natural and artificial silks. The figures indicate the breaking strains in kilograms per square millimeter section:

Natural Silks.

	Dry.	Wet.
Chinese silk.	53.2	46.7
French raw silk.	50.4	40.9
French silk, boiled-off.	25.5	13.6
“ “ dyed red and weighted.	20.0	15.6
“ “ blue-black, weighted 110%	12.1	8.0
“ “ black, weighted 140%	7.9	6.3
“ “ black, weighted 500%	2.2	

Artificial Silks.

Chardonnet's collodion, undyed.	14.7	1.7
Lehner's collodion, undyed.	17.1	4.3
Strehlenert's collodion, undyed.	15.9	3.6
Pauly's cuprammonium, undyed.	19.1	3.2
Viscose silk, early samples.	11.4	3.5
“ “ latest samples.	21.5	
Cotton yarn (for comparison).	11.5	18.6

Cotton may be “animalized”—that is, given the dyeing properties possessed by animal fibres—in a variety of ways.

The material may be impregnated with albumin and afterwards steamed; this method is employed to some extent in printing, being used chiefly in connection with the direct cotton colors, to prevent their bleeding. A solution of casein may also be used instead of albumin, with similar results. The same property may also be imparted to cotton by treatment with tannic acid and gelatin or lanuginic acid, but with doubtful results; though Knecht describes a method which is said to give satisfaction, the cotton being impregnated with a solution of lanuginic acid and allowed to dry in the presence of formaldehyde, when the fibre becomes coated with an insoluble film possessing a remarkable affinity for the substantive dyes. Vignon claims that by treating cotton under pressure with ammonia in presence of zinc chloride or calcium chloride, the fibre acquires an increased affinity for the basic and acid dyestuffs. His results, however, have not been confirmed.

A silk-like appearance may also be given to vegetable fibres by treatment with a solution of silk (fibroin) in some suitable solvent, such as hydrochloric, phosphoric, sulphuric acids, or cuprammonium, etc. The silk employed is made up of scraps and waste which would otherwise be useless. Better results are obtained if the cotton material be treated with a metallic or tannic acid mordant before immersion in the silk solution, and should afterwards be calendered and polished in order to obtain a glossy appearance.

Viscose silk, from solutions of cellulose thiocarbonate, has been made with some degree of commercial success in the United States. It is principally made in coarse numbers, and is used as an artificial horse-hair. Finer numbers of considerable softness have also been made, for use in braids, passementerie, etc.

CHAPTER XIV.

LINEN.

1. Preparation.—Linen is the fibre obtained from the flax plant, botanically known as *Linum usitatissimum*.* The fibre is prepared from the bast of the plant by a process called *retting*, which has for its purpose the separation of the fibrous cellulose from the woody tissue and other plant membranes. Historically, linen appears to have been the earliest vegetable fibre employed industrially, having been used at a much earlier date than cotton. Though grown more or less in every country, at present the cultivation of flax is principally carried on in France, Ireland, Belgium, Holland, Russia, America, and Canada. The bast tissue, which is used for the fibre, is situated between the bark and the underlying woody tissue.

The flax plant, after attaining its proper growth, is either cut down or pulled up by its roots, and subjected to a process technically known as *rippling*, the plants being drawn through a machine which removes the seeds and leaves.† The remaining

* Botanists recognize upwards of one hundred species of the flax plant, but, of all these, the only one possessing industrial importance and the only one readily cultivated is the *Linum usitatissimum* (or *L. commun*), which has a blue flower. The North American Indians have long used the fibre of *L. luvisii*, which differs from the ordinary cultivated flax in having three stems growing from a perennial root. The most ancient species of flax brought under cultivation is thought to be *L. angustifolium*; the Swiss lake-dwellers are said to have grown it, as also the ancient inhabitants of northern Italy. The flax cultivated in the eastern countries, in Assyria, and Egypt appears to have been the common variety *L. usitatissimum*.

† Besides being cultivated for its fibre, the flax plant is also grown for its seed, which yields the valuable oil known as linseed. It possesses good drying qualities,

stalks are then tied in bundles and placed in stagnant water, where they are allowed to remain for a number of days. Active fermentation soon starts, resulting in the decomposition of the woody tissues enclosing the cellulose fibres. When the process has gone sufficiently far, the bundles of fermented stalks are removed and passed through a number of mechanical operations, whereby the decomposed tissues are removed and the linen fibres are isolated in a purified condition. This method of retting with stagnant water is known as "pool-retting." As the fermentation causes the evolution of considerable gas, in order to keep the bundles of stalks submerged they are loaded with stones or boards. The time of steeping in the water varies with circumstances from five to ten days. Another method of retting is to steep in running water. The famous Courtrai flax of Belgium is retted in this manner in the river Lys. The flax-straw, after pulling, is placed in crates and submerged in the water of this stream for a period of four to fifteen days, depending on the temperature and other influences. Courtrai flax is of a creamy color, whereas pool-retted flax is a rather dark bluish brown color. The excellent qualities of the Courtrai flax are said to be due to the action of the soft, slowly running, almost sluggish waters of the river Lys, and to the peculiar ferment existing therein. Another method employed for obtaining the fibre from flax is known as dew-retting, as the flax-straw is spread out in a field and exposed for a couple of weeks to the action of the dew and the sun. Dew-retting, however, gives the most uneven and least valuable product of the three methods employed, and the fibre is rather dark in color. There have also been several chemical methods proposed for retting flax, such as heating with water under pressure, boiling with solutions of oxalic acid, soda-ash, caustic soda, etc. None of these, however, have proved of any industrial value, and the old natural methods are still adhered

and hence is extensively used for the preparation of paints and varnishes. The best seed-flax is grown in tropical and subtropical countries, whereas the best fibre-flax is grown in more northern climates. The seed obtained from the latter variety, though utilized as a by-product, produces only an inferior grade of oil. The oil-cake left after expressing the oil from the seed is an excellent cattle-food and is largely used for this purpose.

to. Additions of various chemicals to the retting waters have at times proved of value, hydrochloric or sulphuric acid sometimes being used to advantage.*

The intercellular substance holding the flax fibres together consists mostly of calcium pectate, and the real object of retting is to render this substance soluble so that it may be removed by the after-processes of treatment. Winogradsky has succeeded in isolating the particular organism that is the active agent in the pectin fermentation. It is an anærobic bacillus which readily ferments pectin matters, but has no action on cellulose. By adding salts promoting the growth of the bacillus to the water employed in retting, it has been found possible to reduce the time of retting very considerably. It has been claimed that fatty acids exert a solvent action on the resinous and pectin matters present in vegetable fibres, and a method for the decortication of flax and other bast fibres has been devised as follows: The raw fibres are impregnated with boiling soap solutions, after which ammonium chloride is added, which liberates the fatty acids. After several hours' treatment these dissolve all gummy and resinous matters; the fibres are then treated with weak caustic alkali, after which they are washed and dried, when they should be thoroughly disintegrated. Ramie may be treated with borated water. Good results are said to be obtained by this method.

The flax stalks, after rippling and being deprived of their leaves and seeds, are known as flax-straw. The latter in the air-dry condition contains from 73 to 80 per cent. of wood, marrow, and bark, and 20 to 27 per cent. of bast. The general structure of flax-straw, and of bast stalks in general, is shown in the schematic drawing (Fig. 38).

The linen fibre as it is obtained from the plant and as it appears in trade is in the form of filaments the length of which varies

* Schenk's method of retting is to steep in warm water, a constant temperature of 35° C. being maintained. It is said that the fermentation may be completed by this method in fifty to sixty hours, and gives a larger yield and a better product than the natural processes of retting. In steam-retting, the bundles of flax-straw are placed in iron cylinders and heated with live steam or hot water under pressure; but the process does not appear to be successful.

considerably with the manner and care employed in decorticating, and may be from a few inches to several feet. These filaments are composed structurally of small elements or cells. Wiesner gives the following dimensions of several varieties of flax filaments:

Kind of Flax.	Mean Length of the Purified Flax Fibre. mm.	Mean Breadth. mm.
Egyptian.	960	0.255
Westphalian.	750	0.114
Belgian Courtrai.	370	0.105
Austrian.	410	0.202
Prussian.	280	0.119

2. Chemical and Physical Properties.—The flax fibre appears to consist of pure cellulose* and shows no signs at all of being lignified. It is strongly swollen by treatment with Schweitzer's reagent, but, unlike cotton, it does not completely dissolve therein.†

The *color* of the best varieties of flax is a pale yellowish white. Flax retted by means of stagnant water, or by dew, is a steel-gray; and Egyptian flax is a pearl-gray. The pale-yellow color of flax is due to natural pigment, but the other color arises from the decomposition of the intercellular matter, which is left as a stain on the fibre. Flax that has been imperfectly retted shows a

* In order to isolate pure flax cellulose, Cross and Bevan have recommended the following procedure: The non-cellulosic constituents of flax are pectic compounds which are soluble in boiling alkaline solutions. The proportion of such constituents varies from 14 to 33 per cent. in different varieties of flax. They may be completely extracted by first boiling the fibre in a dilute solution of caustic soda (1 to 2 per cent.); the residue will consist of flax cellulose, with small remnants of woody and cuticular tissue, together with some of the oils and waxes associated with the latter. By treatment with a weak solution of chloride of lime, the woody tissue is decomposed, and is then removed by again boiling in dilute alkali. The remaining cellulose is then further purified from residual fatty and waxy matters by boiling with alcohol and finally with ether-alcohol mixture. Flax cellulose prepared in this manner appears to be chemically indistinguishable from cotton cellulose.

† In swelling, the fibre blisters considerably, but not in as regular a manner as cotton. The inner layers of the cell withstand the action of the reagent the longest and remain floating in the liquid, like the cuticle of cotton. Parenchyma and intercellular matter adhering to the fibre also remain undissolved in the reagent.

greenish color. The natural color of linen is readily bleached by solutions of chloride of lime in a manner similar to the bleaching of cotton. But the linen fibre suffers considerable deterioration thereby. There are four grades of linen-bleaching—quarter, half, three-quarters, and full bleach. The whiter the fibre is bleached, the weaker it becomes. The *lustre* of linen is quite pronounced and almost silky in appearance; flax that is overretted is dull in appearance. Egyptian flax is also dull, due to the cells being coated with residual intercellular matter.

The flax fibre is much stronger than that of cotton, though overretted flax is brittle and weak.

The bast-cells of the flax fibre may be isolated by treatment with a dilute chromic acid solution. They are cylindrical in

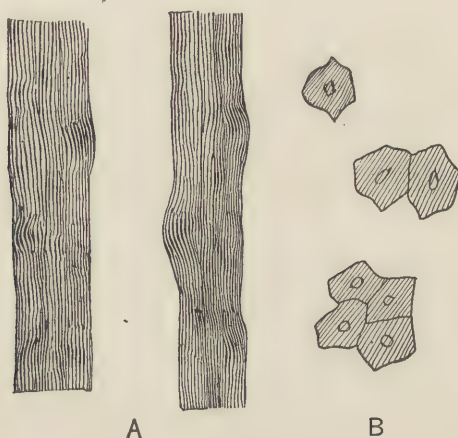


FIG. 37a.—Micrograph of Flax Fibre.

A, longitudinal view, showing jointed structure and tracing of lumen; B, cross-sections.

form and taper to a point at each end. At the middle they measure 12 to 26 μ , with an average of about 15 μ .* The length varies from 4 to 66 mm., with an average of about 25 mm. The ratio of the length of the fibre to its breadth is about 1200. Under the microscope the surface of the fibre appears smooth or marked longitudinally, with frequent trans-

* According to Vétillard, 15-37 μ with an average of 22 μ .

verse fissure lines and jointed structures. On treatment with chloriodide of zinc the latter are colored much darker than the rest of the fibre and are thus rendered more apparent. The lumen appears in the centre of the fibre as a narrow yellow line, and it is usually completely filled with protoplasm. In cross-section the fibres of flax are polygonal, with rounded edges, show a large lumen, and a relatively thin cell-wall. In these respects they are very similar to hemp, but may be distinguished from the latter, however, in that they do not aggregate in thick bundles, but are more or less isolated from each other, so that the cross-section frequently shows but one fibre, and seldom more than three or four* (see Fig. 37*a*).

The following analyses show the composition of two typical specimens of flax (H. Müller):

	I. Per Cent.	II. Per Cent.
Water (hygroscopic).....	8.65	10.70
Aqueous extract.....	3.65	6.02
Fat and wax.....	2.39	2.37
Cellulose.....	82.57	71.50
Ash (mineral matter).....	0.70	1.32
Intercellular matter.....	2.74	9.41

Highly purified flax appears to approximate very closely to the composition of cotton. The ordinary flax fibre of trade may be said to contain about 5 per cent. less of cellulose than cotton, there being about that much more impurity present in the form of intercellular matter and pectin bodies.† The hygroscopic

* Other differences from hemp exhibited by the linen fibre are: (a) the cross-section does not show an external yellow layer of lignin when treated with iodine and sulphuric acid; (b) it gives reactions for pure cellulose only, that is, iodine and sulphuric acid color the fibre a pure blue, and aniline sulphate gives no color, though at times there are shreds of parenchym tissue present which are colored yellow by this latter reagent and appear to be lignified; (c) the lumen of the hemp fibre is seldom filled with yellowish protoplasm like that of the linen fibre; (d) the linen fibres end in sharp points, whereas those of hemp do not.

† The flax fibre contains a certain wax-like substance, varying in amount from 0.5 to 2 per cent. It may be extracted from the fibre by means of benzene or ether. The color of the wax obtained varies with that of the flax from which it is obtained. It has a rather unpleasant odor, resembling flax itself. Its melting-point is 61.5° C., and its specific gravity at 60° F. is 0.9083. According to Hofmeister this wax consists of 81.32 per cent. of unsaponifiable waxy matter and

moisture in linen is about the same as in cotton; in fact, all vegetable fibres appear to contain approximately the same amount (from 8 to 10 per cent.).

Due to differences in structure, linen is more easily disintegrated than cotton, and consequently does not withstand the action of boiling alkaline solutions, solutions of bleaching powder or other oxidizing agents, etc., as well as cotton.

Towards mordants and dyestuffs, etc., linen does not react as readily as cotton, hence its manipulation in dyeing is more difficult. In general, however, it may be said that the dyeing and treatment of linen are practically the same as with cotton.

The oil-wax group of constituents in the flax fibre plays an important part in the spinning of this fibre, and the failure of many of the artificial processes of retting flax may be attributed to the fact that the fibre is left with a deficiency of these constituents. In the breaking down of the cuticular celluloses, whether in the retting or in the bleaching processes, these waxes and oils are separated. Their complete elimination from the cloth necessitates a very elaborate treatment, such as is represented by the "Belfast Linen Bleach."

18.68 per cent. of saponifiable oil. Of the latter, 54.49 per cent. is free fatty acid. The waxy matter has a melting-point of 68° C., and apparently is a mixture of several bodies. The principal one resembles ceresin, and there is also present ceryl alcohol and phylosterin. The saponifiable matter appears to contain small quantities of soluble fatty acids, like caproic, stearic, palmitic, oleic, linolic, linolenic, and isolinolenic.

CHAPTER XV.

JUTE, RAMIE, HEMP, AND MINOR VEGETABLE FIBRES.

1. **Jute** is a fibre obtained from the bast of various species of *Corchorus*, growing principally in India and the East Indian Islands. The most important variety is *Corchorus capsularis*, which is grown throughout tropical Asia not only as a fibre-plant, but also as a vegetable. Other varieties are *C. olitorius*, *C. fuscus*, and *C. decemangulatus*; the latter two, however, yield but a small proportion of the jute fibre to be found in trade.* The jute plant grows to a height of 10 to 12 ft. and its fibrous layer is very thick, so that it yields from two to five times as much fibre as flax.

The preparation of the fibre from the jute plant is a rather simple operation. The stalks are freed from leaves, seed-capsules, etc., and retted by steeping in a sluggish stream of water. After a few days the bast becomes disintegrated, and the retted stalks are pressed and scutched. The fibre so obtained is remarkably pure and free from adhering woody fibre and other tissue. The prepared fibre usually has a length of from 4 to 7 ft., possesses a pale yellowish brown color, and exhibits considerable lustre and tensile strength. The ends of the plant, together with the various short waste fibres, appear in trade under the name of "jute butts" or "jute cuttings," and are employed as a raw material for paper-manufacturing.

* The commercial fibre known as Chinese jute is not a variety of jute at all, but is derived from *Abutilon avicennæ* or Indian mallow. The latter grows extensively as a weed in America. The bast fibre is white and glossy, and has considerable tensile strength. It is also used for the making of paper stock. Chemically it appears to consist of bastose, and hence resembles jute in its behavior towards dyestuffs. The plant produces about 20 per cent. of fibre, but is of doubtful economic value.

According to Höhnelt the bast-cells of the jute fibre are 1.5 to 5 mm. in length, and from 20 to 25 μ in thickness, the mean ratio of the length to the breadth being about 90; consequently the elements of the jute fibre are relatively short. In cross-section the jute fibre shows a bundle of several elements bound together; these are more or less polygonal in outline, with sharply defined angles. Between the separate elements is a narrow median layer (see Figs. 40 and 41), which, however, does not give a much darker color with iodine and sulphuric acid than the cell-wall itself. The lumen is about as wide, or at times even wider, than the cell-wall, and in cross-section is round or oval. Longitudinally, the lumen shows remarkable constrictions (see Fig. 39), though towards the end of the fibre the lumen broadens out considerably, causing the cell-wall to become very thin. Externally the fibre is smooth and lustrous, and has no jointed ridges or transverse markings such as seen in linen or most other bast fibres.

In its chemical composition jute is apparently quite different from linen and cotton, being composed of a modified form of cellulose known as lignocellulose or bastose. Bastose, properly speaking, is a compound of cellulose with lignin.* It behaves quite differently from cellulose towards various reagents, its chief distinction being that it is colored yellow by iodine and sulphuric acid, whereas pure cellulose is colored blue. The following table gives the principal reactions used to distinguish cellulose from bastose:

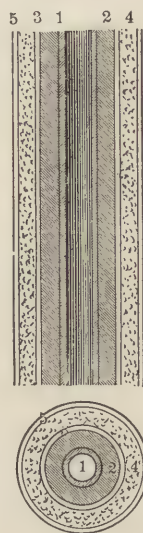


FIG. 38.—Diagram of Flax-straw. (Witt.)
1, marrow; 2, woody fibre; 3, cambium layer; 4, bast fibre; 5, rind or bark.

* Müller gives the following method for the isolation of pure cellulose from jute: Two grams of the material are dried at 110° to 115° C. In order to remove wax, etc., it is next treated with a mixture of alcohol and benzol, and is subsequently boiled with very dilute ammonia water. The softened mass is then

Reagent.	Cellulose.	Bastose.
Iodin and sulphuric acid.	Blue color	Yellow to brown color
Anilin sulphate and sulphuric acid.	No change	Deep-yellow color
Basic dyestuffs.	No change	Becomes colored
Weak oxidizing agents ...	No change	Quickly decomposes
Schweitzer's reagent.	Quickly dissolves	Swells, becomes blue, and slowly dissolves

Analysis of the jute fibre shows it to consist of the following:

Constituents.	Nearly Colorless Specimen.	Fawn-colored Fibre.	Brown Cuttings.
Ash.	0.68		
Water (hygroscopic).	9.93	9.64	12.58
Aqueous extract.	1.03	1.63	3.94
Fat and wax.	0.39	0.32	0.45
Cellulose.	64.24	63.05	61.74
Incrusting and pectin matters.	24.41	25.36	21.29

The ash of jute consists principally of silica, lime, and phosphoric acid; manganese is nearly always present in small amount.*

Bastose is dissolved by the usual cellulose solvents, such as zinc chloride and Schweitzer's reagent; and from these solutions the lignocellulose may be precipitated by dilution or acidifying, respectively, though the precipitation is never complete, there remaining in solution about 15 to 25 per cent. of the original substance.

pulverized in a mortar, and placed in a large, glass-stoppered flask with 100 c.c. of water. From 5 to 10 c.c. of a solution of 2 c.c. of bromin in 500 c.c. of water are added, until a permanent yellow color is obtained after standing twelve to twenty-four hours. The substance is then filtered, washed with water, and heated to boiling with water containing a little ammonia. After this it is filtered, washed, and again treated with the bromin solution, as above indicated, until a permanent yellow color is obtained. The fibre is then boiled with dilute ammonia, and on filtering and washing leaves a residue of pure white cellulose.

* According to Cross and Bevan the jute fibre may be regarded as an anhydro-aggregate of three separate compounds: (a) A dextracellulose allied to cotton; (b) a pentacellulose yielding furfural and acetic acid on hydrolysis; (c) lignone, a quinone which is converted by chlorination and reduction into derivatives of the trihydric phenols.

The chief chemical difference between jute and the pure cellulose fibres is in the ability of the former to combine directly with basic dyestuffs. In fact, it acts in this respect similar to

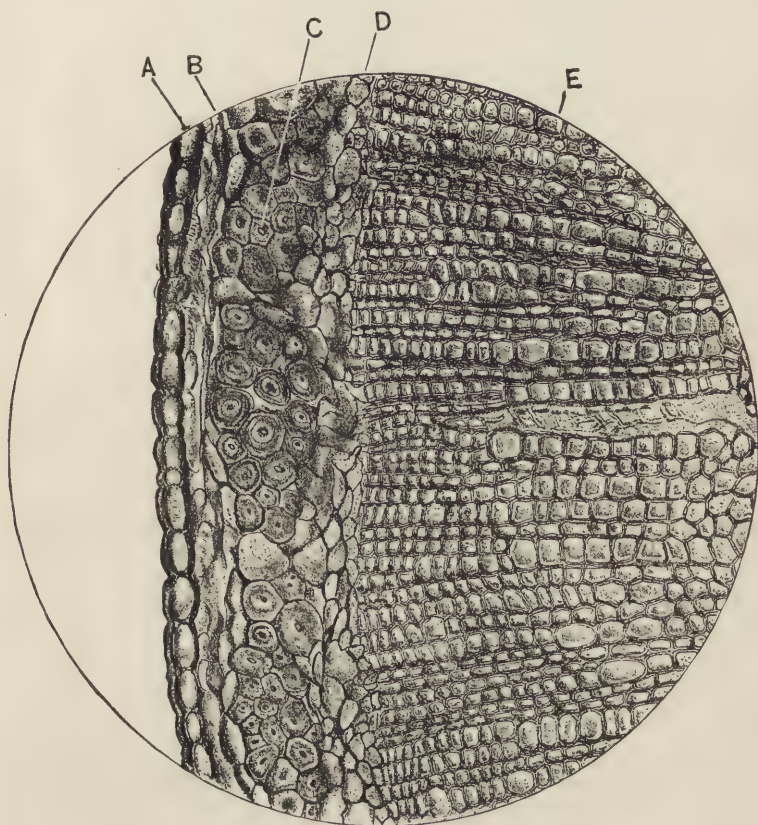


FIG. 39.—Cross-section of Flax-straw. (Cross & Bevan.)

A, layer of cuticular cells; *B*, intermediate layer of cortical parenchyma; *C*, bast fibres in groups, being the flax fibres proper; note secondary thickening of cell-walls; *D*, cambium layer; *E*, woody tissue.

cotton which has been mordanted with tannic acid. Jute is also more sensitive to the action of chemicals in general than cotton or linen. On this account it cannot be bleached with much success, as treatment with alkalis and bleaching powder weakens and disintegrates the fibre to a considerable extent.

The jute fibre is relatively weak when compared with other bast fibres, and the chief reasons for its prominence among the textile fibres are its fineness, silk-like lustre, and adaptability for spinning. The plant is also easy to cultivate, and returns a large yield of fibre. The chief defect of jute is its lack of durability; when exposed to dampness it rapidly deteriorates; and even under ordinary conditions of wear, the fibre gradually becomes brittle and loses much of its strength. The bleached fibre is especially liable to such deterioration; it gradually loses its whiteness, and, evidently due to oxidation, becomes dingy and yellowish brown in color.

Jute is principally used for the making of coarse woven fabrics, such as gunny sacks and bagging, where cheapness is of more consequence than durability. It also finds considerable use in the tapestry trade, being used as a binding-thread in the weaving of carpets and rugs. On account of its high lustre and fineness, it is also adapted for the preparation of cheap pile fabrics for use in upholstery. Of late years a variety of novelty fabrics for dress-goods have also been made from jute, used in conjunction with woolen yarns. Jute has also been used extensively as a substitute for hemp, for which purpose the former is rendered very soft and pliable by treatment with water and oil. A mixture of 20 parts of water with 2.5 parts of oil is sprinkled over 100 parts of jute fibre. It is left for one to two days, then squeezed and heckled, whereby the fibres become very soft and isolated. Jute is also largely used in the manufacture of twine and smaller sizes of rope. Owing to its cheapness it is used to adulterate other more valuable fibres, but due to its tendency to rapid deterioration, its use in this connection should not be encouraged. The "jute butts" and miscellaneous waste are extensively employed as a raw material in the manufacture of paper.

2. **Ramie**, or **China Grass**, is a fibre obtained from the bast of the stingless nettle, or *Bæhmeria*. Although frequently confounded in trade, ramie and China grass are in reality two distinct fibres. The former (also known as rhea) is obtained from the *Bæhmeria tenacissima*, which grows best in tropical and sub-tropical countries. The latter is obtained from *Bæhmeria nivea*, which grows principally in the more temperate climes. The

two species, however, are so similar in nature, and the fibres are so universally confounded with one another, that it is only possible to consider them as a single substance, which will be done under the name of ramie. The plant is a shrub, reaching 4 to 6 ft. in height, and is very hardy. It is cultivated largely in China and India, and has also been grown successfully in America.

The fibre of ramie is very strong and durable, probably ranking first of all vegetable fibres in this respect. It is also the least affected by moisture. It has three times the strength of hemp, and the fibres can be separated to almost the fineness of silk. The fibre is exceptionably white in color, being almost comparable to bleached cotton in this respect, and does not appear to have any natural coloring-matter at all. It also has a high lustre, excelling linen in this respect.

The following table gives the chief physical factors of the ramie fibre in comparison with the other principal fibres:

	Ramie.	Hemp.	Flax.	Silk.	Cotton.
Tension.....	100	36	25	13	12
Elasticity.....	100	75	66	400	100
Torsion.....	100	95	80	600	400

Having such excellent qualities as a fibre, it would be natural that ramie should have had considerable attention bestowed upon it. The chief difficulty in the way of its universal and wide-spread adoption has been the lack of an efficient process for properly decorticating the fibre from the rest of the plant. In China and India, where this fibre has long been employed for the weaving of the finest and most beautiful fabrics, the decortication of the fibre is carried out by hand. This, of course, would be impracticable in western countries.

On French authority it is stated that the yield of decorticated fibre from the green, unstripped stalks amounts to about 2 per cent., and of degummed fibre about 1 per cent. Based on the weight of dry, stripped stalks, the yield of the degummed fibre would be about 10 per cent.

The bast of the ramie cannot be removed from the woody tissue in which it is imbedded by a simple retting, as in the case of flax and other bast fibres. It must undergo a severe mechanical treatment, whereby the outer bark is removed. The long, fibrous tissue so obtained consists of the ramie filaments held together in the form of a ribbon by a large quantity of gum, and before the fibres can be combed out this gum must be removed by chemical treatment. The gummy matters seem to consist essentially of pectose, cutose, and vasculose. In the degumming, the object is to remove these substances without affecting the cellulose of the fibre proper. The vasculose and cutose may be dissolved by treatment with alkaline oleates or caustic alkalies employed under pressure. The adhering pectose can then be detached mechanically by washing.

Though ramie has many excellent qualities to recommend it as a textile fibre for definite uses, nevertheless it lacks the elas-

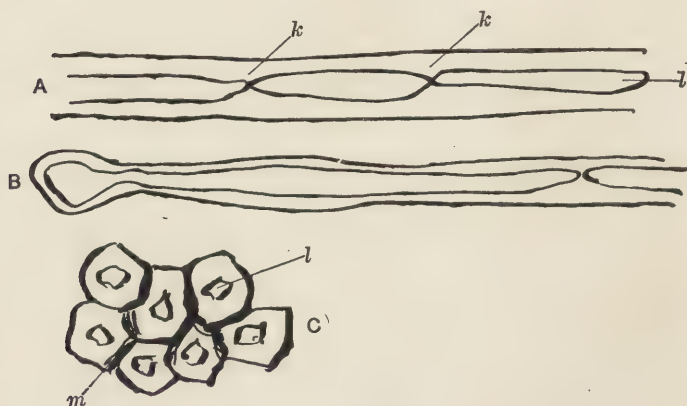


FIG. 40.—Jute Fibre.

A, middle portion; B, end of fibres; *l*, lumen; *k*, knot-like joints; C, cross-sections; *m*, median layers between fibres.

ticity of wool and silk and the flexibility of cotton. As a result it yields a harsher fabric, which has not the softness of cotton. Owing to its smooth and regular surface it also becomes difficult to spin into fine counts, as the fibres lack cohesion and will not adhere to each other.

Microscopically, the ramie fibre is remarkable for the large size of its bast-cells. These are from 60 to 250 μ in length and up to 80 μ in width. The ratio of the length to the breadth is about 2400. The fibre consists of pure cellulose with no indication of the presence of any lignin. Along the fibre, joints and transverse fissures are of frequent occurrence (see Fig. 42). The lumen is especially broad and easily noticeable. The ends of the fibre elements have a thick-walled, rounded point, and the lumen is reduced to a line. The cross-section of the fibre (see Fig. 43) shows usually only a single element or a group of but a few members. The cross-section is also quite large, and is elliptical in shape; the lumen appears open, and frequently contains granular matter. The cross-section also frequently shows strong evidence of stratification. The fibres are frequently very broad, and at these parts are flat and ribbon-like in form, but are never twisted (see Fig. 44).

Müller gives the following analysis of the raw fibre of samples of both China grass and ramie:

Constituent.	China Grass.	Ramie.
Ash.	2.87	5.63
Water (hygroscopic).	9.05	10.15
Aqueous extract.	6.47	10.34
Fat and wax.	0.21	0.59
Cellulose.	78.07	66.22
Intercellular substances and pectin.	6.10	12.70

3. Hemp is a name applied to a large number of bast fibres more or less analogous in appearance and properties.* Hemp

* Among the different varieties of hemp appearing in trade may be enumerated the following (Dodge):

Ambari (or brown) hemp	<i>Hibiscus cannabinus</i>
Bengal (or Bombay) hemp.	<i>Crotalaria juncea</i>
Black-fellow's hemp.	<i>Commersonia fraseri</i>
Bowstring hemp (Africa).	<i>Sansevieria guineensis</i>
Bowstring hemp (India).	<i>S. roxburghiana</i>
Bowstring hemp (Florida).	<i>S. longiflora</i>
Calcutta hemp.	<i>Jute</i>
Cebu hemp.	<i>Musa textilis</i>
Colorado River hemp.	<i>Sesbania macrocarpa</i>

proper, or the so-called *common hemp*, is derived from the bast of *Cannabis sativa*. This is a shrub growing from 6 to 15 ft. in height, and though originally a native of India and Persia, it is now cultivated in nearly all the temperate and tropical countries of the world. At the present time it is quite extensively grown in America, though not as yet in sufficient amount to satisfy the home consumption. Russia produces an enormous quantity of hemp; in fact, this fibre forms one of that country's staple articles of export. Poland is also a large producer. French hemp, though not grown to such an extent, is much superior in quality to that from either Russia or Poland, it being fine, white, and lustrous. Italian hemp is also of a very high grade. In India hemp is not grown so much for its fibre as for the narcotic products obtained. Japanese hemp is of excellent quality, and appears in trade in the form of very thin ribbons, smooth and glossy, of a light straw color, and the frayed ends showing a fibre of exceeding fineness. Hemp appears to have been the oldest textile fibre used in Japan.

Cretan hemp.	<i>Datisca cannabina</i>
Cuban hemp.	<i>Furcraea cubensis</i>
False hemp (American).	<i>Rhus typhina</i>
False sisal hemp.	<i>Agave decipiens</i>
Giant hemp (China).	<i>Cannabis gigantea</i>
Hayti hemp.	<i>Agave fœtida</i>
Ifé hemp.	<i>Sansevieria cylindrica</i>
Indian hemp.	<i>Apocynum cannabinum</i>
Jubbulpore hemp (Madras).	<i>Crotalaria tennifolia</i>
Manila hemp.	<i>Musa textilis</i>
New Zealand hemp (or flax).	<i>Phormium tenax</i>
Pangane hemp.	<i>Sansevieria kirkii</i>
Pita hemp.	<i>Yucca</i> spp.
Pua hemp (India).	<i>Maoutia puya</i>
Queensland hemp.	<i>Sida retusa</i>
Rangoon hemp.	<i>Laportea gigas</i>
Roselle hemp.	<i>Hibiscus sabdariffa</i>
Sisal hemp.	<i>Agave rigida</i>
Sunn hemp.	<i>Crotalaria juncea</i>
Swedish hemp.	<i>Urtica dioica</i>
Tampico hemp.	<i>Agave heteracantha</i>
Water hemp.	<i>Eupatorium cannabinum</i>
Wild hemp.	<i>Maoutia puya</i>

The hemp fibre is obtained from the plant by a process of retting similar to that employed for flax. The method of dew-retting is chiefly used; that is, the stalks are spread out in the fields until the action of the elements causes the woody tissue and gums enclosing the fibres to decompose. Retting in pools

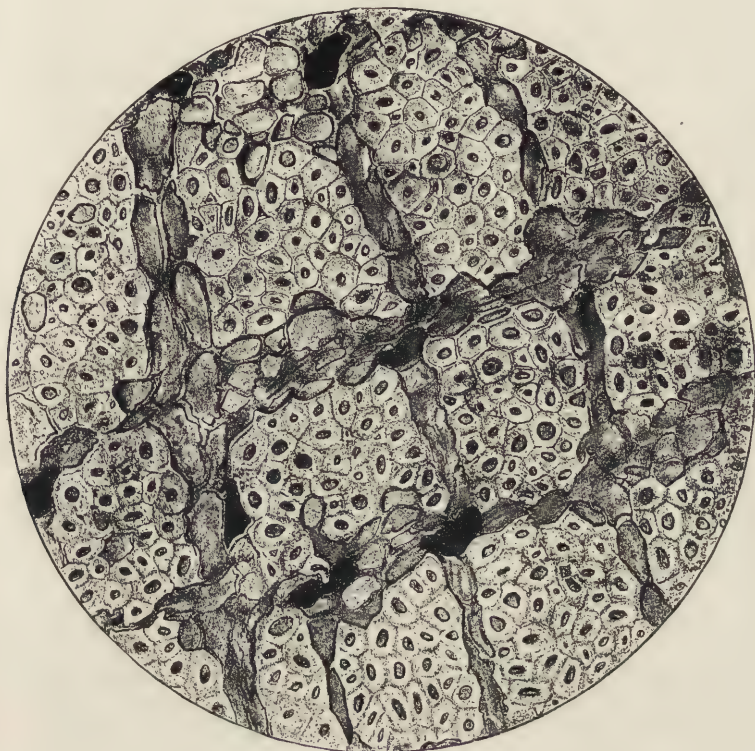


FIG. 41.—Cross-section of Jute-straw. (Cross & Bevan.)
Showing transverse section of portion of bast only, giving the anatomy of the fibrous tissue, the form of the bast-cells, and the thickening of the cell-walls.

of water has been practised to a slight extent, but evidently not with much success. It is said that 100 kilos of raw hemp furnish 25 kilos of raw fibre or filasse; and 100 kilos of the latter yield 65 kilos of combed filasse and 32 kilos of tow.

The seed of the hemp plant, like that from flax, is also utilized for the oil it contains; 100 kilos of seed furnish 27 kilos of oil.

So this forms an extensive and important by-product in the cultivation of hemp.

Under the microscope the hemp fibre is seen to consist of cell elements which are unusually long, averaging about 20 mm. in length, but varying from 5 to 55 mm. The diameter, however, is very small, averaging $22\ \mu$, and varying from 16 to $50\ \mu$. Hence the ratio between the length and diameter is about 1000. The

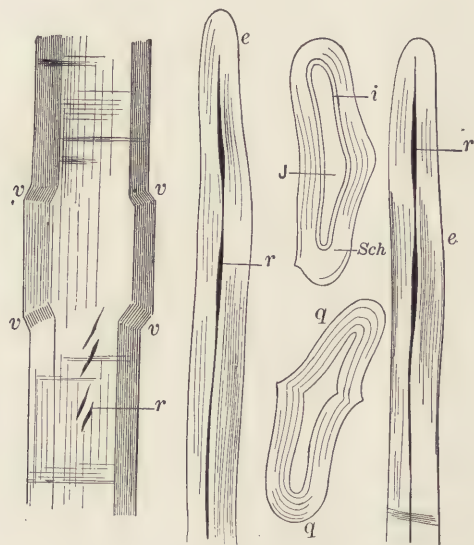


FIG. 42.—Ramie Fibre. (Höhncl.)

v, swollen displacements; *r*, fissures; *e*, point or end; *q*, cross-sections; *i*, inner layers of fibre-wall; *J*, lumen; *sch*, stratifications.

fibre is rather uneven in its diameter, and has occasional attachments of fragmentary lignified tissue. In its linear structure the fibre exhibits frequent joints, longitudinal fractures, and swollen fissures. The lumen is usually broad, but towards the end of the fibre it becomes like a line (see Fig. 45.) It shows scarcely any contents. The ends of the filaments are blunt and very thick-walled, and often possess lateral branches. The cross-section generally shows a group of cells which nearly always have rounded edges and are not so sharp-angled and polygonal as in

the case of jute. There is also a median layer between the cells, which is evidenced by it turning yellow on treatment with iodine and sulphuric acid. In the section the lumen appears irregular and flattened, and does not show any contents. The cell-walls frequently exhibit a remarkable stratification, the different layers

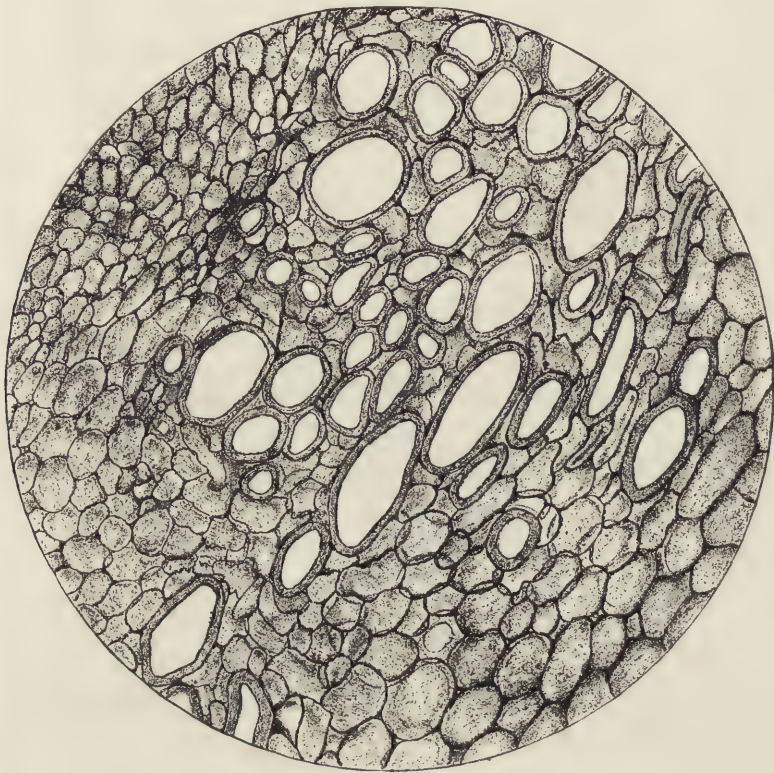


FIG. 43.—Cross-section of Ramie-straw. (Cross & Bevan.)
Showing transverse section of bast region only; the bast fibres are to be distinguished by their large area from the adjacent tissue.

yielding a variety of colors on treatment with iodine and sulphuric acid (see Fig. 46).

Hemp is somewhat difficult to distinguish microscopically from flax; but the two may readily be told by an examination of the ends of the fibres, hemp nearly always exhibiting specimens of forked ends, whereas flax never has this peculiarity. The differ-

ence in the appearance of the cross-sections is also of service in discriminating between these two fibres. Again, the parenchymous tissue which frequently occurs as attached fragments to hemp fibres is rich in star-shaped crystals of calcium oxalate, and this is scarcely ever to be noticed in the case of flax. A peculiarity to be noticed in the examination of hemp is the occasional presence of long narrow cells filled with reddish brown matter, insoluble in

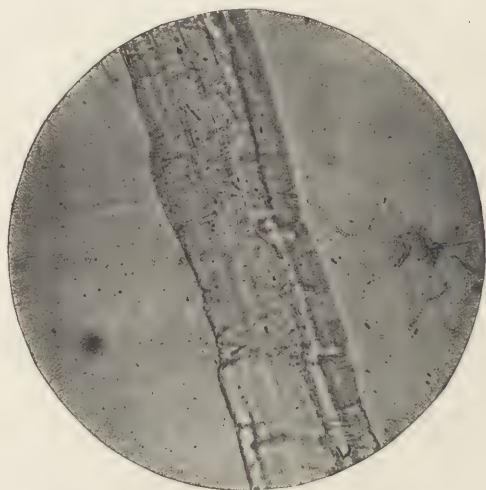


FIG. 44.—Ramie Fibre ($\times 500$).
Showing the longitudinal ridges and knotted-like cross-markings and fissures.

the ordinary solvents. These cells occur between the fibres as well as in the bast, and probably contain tannin. They are not to be found in flax. The behavior of isolated hemp-cells with ammoniacal copper oxide solution is also quite characteristic; the cell membrane acquires a blue to a bluish green color, and swells up like a blister, showing sharply defined longitudinal striations. The inner cell-wall remains undissolved in the form of a spirally wound tube contained inside the strongly swollen mass of the fibre.

The hemp fibre is not composed entirely of pure cellulose, as it gives a green coloration with anilin sulphate, and iodine and sulphuric acid. It appears to be a mixture of cellulose and bas-

tose. Müller gives the following analysis of a sample of best Italian hemp:

	Per Cent.
Ash.	0.82
Water (hygroscopic).	8.88
Aqueous extract.	3.48
Fat and wax.	0.56
Cellulose.	77.77
Intercellular matter and pectin bodies.	9.31

Hemp is principally employed for the manufacture of twine and cordage, for which its great strength eminently adapts it; and besides, it is a very durable fibre, and is not rotted by water. In this respect it differs very essentially from jute. It is seldom used, however, for woven textiles, as it is harsh and stiff, and not sufficiently pliable and elastic. It also possesses a rather dark brown color, and cannot be successfully bleached without serious injury to the quality of the fibre.

4. Sunn Hemp is the bast fibre of the *Crotalaria juncea*; it is also known by the names of Conkanee, Indian, Brown, and Madras hemp. It grows abundantly in the countries of southern Asia, and is largely used in the manufacture of cordage. It appears to have been one of the earliest fibres mentioned in Sanscrit literature. The fibre is obtained from the plant by a system of retting very similar to that of flax. The fibre of sunn hemp is of a better quality than jute, being lighter in color, of a better tensile strength, and more durable to exposure. Dr. Wight gives the following table for the strength of several cordage fibres:

	Pounds
Sunn hemp.	407
Cotton rope.	346
Hemp.	290
Coir.	224

In appearance sunn hemp is very similar to hemp, both to the naked eye and under the microscope. The essential distinction between the two is in the cross-section (see Fig. 47), which shows the presence of a very thick median layer of lignin between

the individual cells. The lumen in the cross-section is also usually rather thick, and often contains yellowish matter, differ-

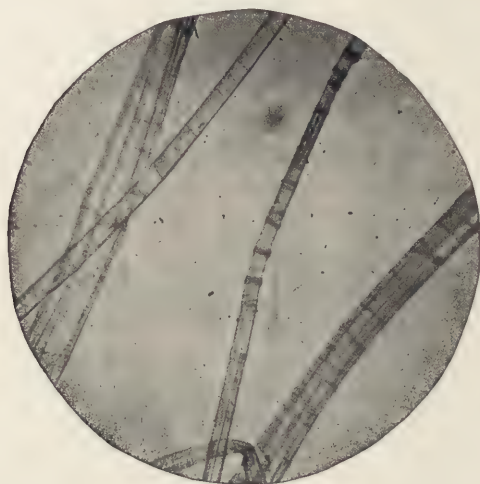


FIG. 45.—Fibres of Hemp ($\times 350$).
Showing longitudinal fissures and numerous transverse cracks and jointed-like structure.

ing in these respects from hemp, in which the lumen is flat and narrow and always empty.

Müller gives the following analysis of raw sunn hemp:

	Per Cent.
Ash.	0.61
Water (hygroscopic).	9.60
Aqueous extract.	2.82
Fat and wax.	0.55
Cellulose.	80.01
Pectin bodies.	6.41

5. Ambari or Gambo Hemp is an East Indian fibre derived from the bast of *Hibiscus cannabinus*. The fibre when carefully prepared is from 5 to 6 feet in length; it is of a lighter color than hemp, and harsher. Its tensile strength is somewhat less than that of sunn hemp. Like the latter fibre, it is principally used for cordage, though it is also employed in India for the manufacture of a coarse canvas. In its microscopic characteristics ambari hemp is very similar to jute; the length of the fibre ele-

ments varies from 2 to 6 mm., and the diameter from 14 to 33 μ . The median layers of lignin between the cells are broad, and are colored much darker than the inner layers of the cell-wall when treated with iodine and sulphuric acid. The lumen presents the same appearance as with jute (see Fig. 48), having such very marked contractions, that in places it is discontinuous. The ends of the fibres are very blunt and thick-walled.

6. **New Zealand Flax** differs somewhat from the preceding fibres in that it is derived, not from the bast, but from the leaves of *Phormium tenax*. Botanically these are known as sclerenchymous fibres. Apart, however, from this histological difference, such fibres are very similar in general structure to ordinary bast fibres. *Phormium tenax* is a native of New Zealand, but is also found distributed in other portions of Australasia; it has been introduced into several European countries, and is also cultivated to quite an extent in California. The fibre of New Zealand flax is very white in color, is soft and flexible, and possesses a high lustre. In tenacity the fibre appears to be superior to either flax or hemp, as is seen by the following comparative figures (Royle):

	Pounds.
New Zealand flax.	23.7
Flax.	11.75
Hemp.	16.75

The leaves of *Phormium tenax* reach over 5 feet in length, and the fibre is separated by first scraping the leaves and then combing out the separate fibres. No process of retting is necessary, as with the bast fibres. The method of preparing the fibre, however, is as yet very unsatisfactory, and could be much improved. The amount of fibre obtained under the present method of operating is from 10 to 14 per cent. on the weight of the leaves, although the latter contain as much as 20 per cent. of fibre.

In their microscopical characteristics the fibres of New Zealand flax are remarkable for their slight adherence. The fibre elements are 5 to 15 mm. in length and 10 to 20 μ in diameter, and the ratio of the length to the breadth is about 550. They are very regular and uniformly thickened, and the surface is smooth,

exhibiting no markings or jointed sutures. The lumen is very apparent, but is generally narrower than the cell-wall and is very uniform in its width. The ends are sharply pointed and not divided. The cross-section shows rather loosely adhering elements (see Fig. 49), and is very round in contour, the lumen being



FIG. 46.

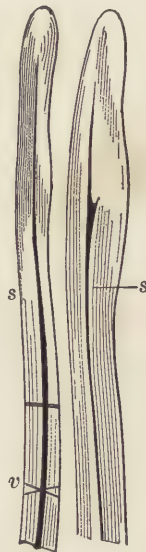


FIG. 47.

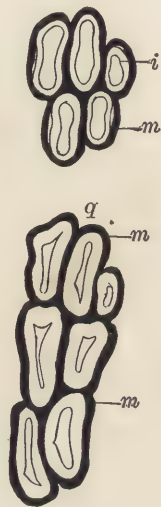


FIG. 46.—Hemp Fibre Showing Stratification. (Höhncl.)

FIG. 47.—Sunn Hemp. (Höhncl.)

L, view of middle portion; *v*, joints; *l*, lumen; *s*, pointed ends; *q*, cross-sections; *m*, outer layer of fibre; *i*, inner layers.

either round or oval, and is empty. No median layer of lignin is apparent between the elements, though the fibres themselves are completely lignified. The purified fibre of New Zealand flax is rather difficult to distinguish microscopically from aloe hemp or from *Sansevieria* fibre, except by the rounded and separated cross-sections. The fibre also usually contains a substance derived from the sap of the leaf which possesses the peculiarity of giving a deep-red color with concentrated nitric acid. The composition of the fibre is as follows (Church):

	Per Cent.
Ash.	0.63
Water.	11.61
Gum (and other matter soluble in water).	21.99
Fat.	1.08
Pectin bodies.	1.69
Cellulose.	63.00

New Zealand flax is principally employed in the making of cordage and twine and floor-matting, though the best fibre can

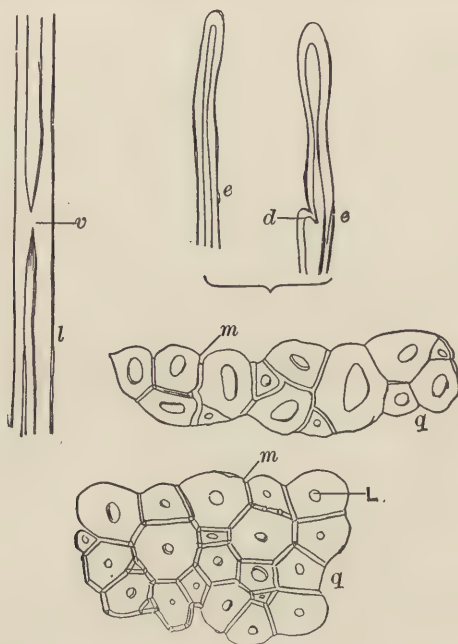


FIG. 48.—Gambo Hemp. (Höhncl.)

e, ends with blunt points and wide lumen; *d*, lateral branch; *l*, longitudinal cutting, with *v*, interruptions in lumen; *q*, cross-sections, with *L*, small lumen; *m*, median layers.

also be woven into cloth resembling linen duck. It has been used extensively in the United States for the making of "staff," being mixed with plaster for this purpose. The chief drawback to the fibre of New Zealand flax is its poor resistance to water.

7. Manila Hemp is the fibre obtained from the leaf-stalks of the *Musa textilis*, a variety of plantain which is a native of the

Philippine Islands. The fibre is white and lustrous in appearance, light and stiff in handle, and easily separated. It is also a very strong fibre, and of great durability. In the Philippines it is known as *abaca*. The coarser fibres are used for the manufacture of cordage, for which purpose it is eminently suited on account of its great strength. The relative strengths of rope made from English hemp and that made from Manila hemp are about 10 to 12 respectively. The finer fibres, which require to be selected and carefully prepared, are woven into a very high grade of muslin, which brings a good price, even in Manila. Under the microscope Manila hemp shows fibre elements of 3 to 12 mm. in length, and 16 to 32 μ in width, the ratio of the length to the diameter being about 250. The bundles of fibres are very large, but by treatment with an alkaline bath are easily separated into smooth, even fibres. The fibres are very uniform in diameter, are lustrous, and are rather thin-walled. The lumen is large and distinct, but otherwise the fibre does not exhibit any markings. The cross-sections are irregularly round or oval in shape, and the lumen in the section is open and quite large and distinct (see Fig. 50). The fibre-bundles frequently show a series of peculiar, thick, strongly silicified plates, known as stegmata. Lengthwise these appear quadrilateral and solid, and have serrated edges and a round, bright spot in the centre. The stegmata may be best observed after macerating the fibre-bundles in chromic acid solution; they are about 30 μ in length. On extracting the fibre with nitric acid, then igniting, and adding dilute acid to the ash so obtained, the stegmata will appear in the form of a string of pearls, frequently in long chains with sausage-like links, a very peculiar and characteristic appearance. The lumen often contains a yellowish substance, but no distinct median layer is perceptible between the fibres. Manila hemp is a lignified fibre, and gives a yellow color with anilin sulphate; iodine and sulphuric acid give a golden-yellow to a green color; ammoniacal copper oxide causes a blue coloration and a slight swelling.* According to Müller the composition of Manila hemp is as follows:

* Besides the *Musa textilis*, the fibre from the following varieties is also utilized: *Musa paradisiaca*, *M. sapientium*, and *M. mindanensis* from India and islands in the Pacific Ocean; *M. cavendishii* from China; *M. eusei* from Africa.

	Per Cent.
Ash.	1.02
Water.	11.85
Aqueous extract.	0.97
Fat and wax.	0.63
Cellulose.	64.72
Incrusting and pectin matters.	21.83

8. **Sisal Hemp** is the fibre obtained from the leaves of the *Agave rigada*, a native of Central America; it is also grown in the islands of the West Indies and in Florida. The fibre has a light yellowish color, and is very straight and smooth; it is principally used for making cordage, for which purpose it is quite valuable, as it is second only to Manila hemp in tensile strength. The fibre is easily separated from the leaf, and does not require a retting process. In their microscopical appearance the fibre-bundles often show an interlaced formation with a peculiar spiral thickening. The fibre elements are 1.5 to 4 mm. in length, and 20 to 32 μ in breadth, the ratio of the length to the diameter being about 100. They are usually quite stiff in texture, and show a remarkable broadening towards the middle. The width of the lumen is frequently greater than that of the cell-wall. The ends are broad, blunt, and thick, but seldom forked. The cross-sections are colored yellow by iodine and sulphuric acid, and show no evidence of a median layer between the elements. The sections are polygonal in outline, but often have rounded edges, and the bundles are usually close together. The lumen in the cross-section is large, and polygonal in shape, though the edges of the lumen are more rounded than those of the walls. The ash obtained from the ignition of the fibre shows the presence of glistening crystals of calcium carbonate, which are derived from the original crystals of calcium oxalate to be found clinging to the fibre-bundles. They are usually in longitudinal series, about 0.5 mm. long, and taper off at the ends to a chisel shape, resembling a thick needle in form, but having a quadrilateral cross-section.

9. **Aloe Fibre**, or **Mauritius hemp**, is obtained from the leaf of various species of aloe plants, growing in tropical climates. This fibre is often confounded with that of the *Agave americana*, but

it is of different origin. Aloe fibre, however, is very similar to *Sansevieria* fibre, and is hardly to be distinguished from it in either physical or microscopic appearance. The fibre elements are 1.3 to 3.7 mm. in length, and 15 to 24 μ in breadth. Although

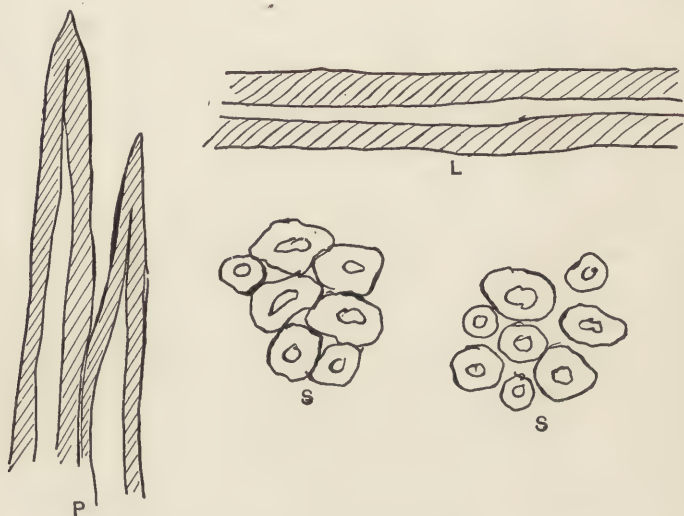


FIG. 49.—New Zealand Flax.

P, view of pointed ends; L, view of middle portion; S, cross-sections.

uniformly broad, the cell-wall is thin. The fibres are usually cylindrical and not flattened; they show occasional fissure-like pores (see Fig. 51). The cross-sections are polygonal, with slightly rounded edges. The lumen is usually somewhat broader than the walls, and in the cross-section is polygonal, with rounded sides. In the *Sansevieria* fibre the lumen in the cross-section is usually larger, and the cell-walls consequently thinner; furthermore the lumen has a sharp-edged, polygonal form (see Fig. 51).

10. **Pita Fibre** is obtained from the leaf of the *Agave americana*, or century plant; it is also known as aloe fibre. The fibre is white to pale straw in color, is stiff and short, has a rather thin wall, and furthermore is liable to rot. The fibres have a distinctive wavy appearance, and another peculiarity is its great elasticity. According to Royle, Indian pita has been found

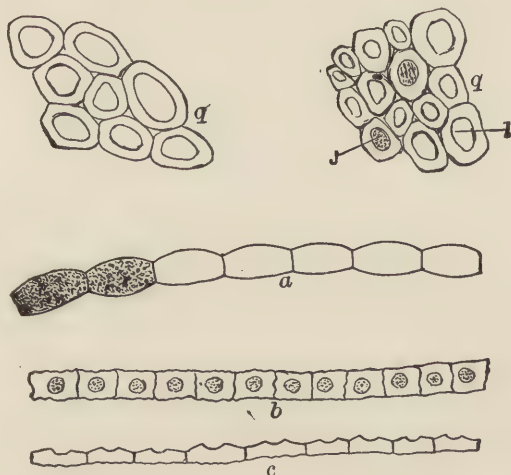


FIG. 50.—Manila Hemp. (Höhnel.)

q, cross-sections; l, lumen without contents; j, lumen containing granular matter; a, silicious skeleton of the stegmata; b, rows of stegmata, flat side; c, the same, narrow side.

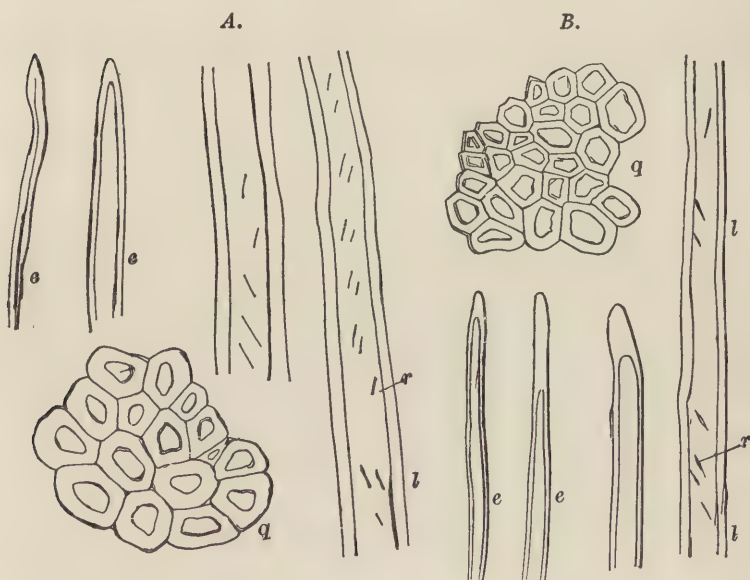


FIG. 51.—Aloe Fibre. (Höhnel.)

A, from *Aloe speciosus*; B, from *Sansevieria*. e, ends; l, longitudinal view; q, cross-sections; r, fissure-like pores in cell-walls.

superior in strength to either coir, jute, or sunn hemp, the breaking strain on similar ropes made of these materials being as follows:

	Pounds.
Pita.....	2519
Coir.....	2175
Jute.....	2456
Sunn hemp.....	2269

Russian hemp and pita, on comparison, gave a relative strength of 16 to 27. Besides its use as a cordage fibre, pita is also employed for the making of a very delicate and beautiful lace known as Fayal. In its microscopical characteristics pita is very similar to sisal hemp.

11. Pineapple Fibre, or Silk Grass, is obtained from *Ananas sativa*, or pineapple plant. This fibre has great durability and is unaffected by water. It is very fine in staple and highly lustrous, and is white, soft, and flexible. It is used in the manufacture of the celebrated *piña* cloth in the Philippine Islands. According to Taylor, a specimen of this fibre was subdivided to one ten-thousandth of an inch in thickness, and was considered to be the most delicate in structure of any known vegetable fibre. Microscopically it is distinguished from all other leaf fibres, in fact, by the extreme fineness of its fibre elements. These are 3 to 9 mm. in length and 4 to 8 μ in thickness. The lumen is very narrow and appears like a line. The cross-sections are polygonal in outline and frequently flattened. The sections form compact groups which are often crescent-shaped, and are enclosed in a thick median layer of lignified tissue.

12. Coir Fibre is obtained from the fibrous shell of the coconut. The fibre occurs in the form of large, stiff, and very elastic filaments, each individual of which is round, smooth, and somewhat resembling horsehair. It possesses remarkable tenacity and curls easily. In color it is cinnamon-brown. It possesses marked microscopical characteristics; the fibre elements are short and stiff, being 0.4 to 1 mm. in length and 12 to 24 μ in diameter; the ratio of the length to the thickness is only 35. The cell-wall is thick, but rather irregularly so, in consequence of which the lumen has an irregular outline, resembling indentations (see Fig.

52). The points terminate abruptly and are not sharp, and there appear to be a large number of pore-canals penetrating the cell-wall. On the external surface the fibre-bundles are occasionally covered with small lens-shaped, silicified stegmata, about $15\ \mu$ in breadth. These stegmata fuse together on ignition, giving a blister on the ash. If the fibre is boiled with nitric acid previous to its ignition, the stegmata then appear in the ash like yeast-cells,

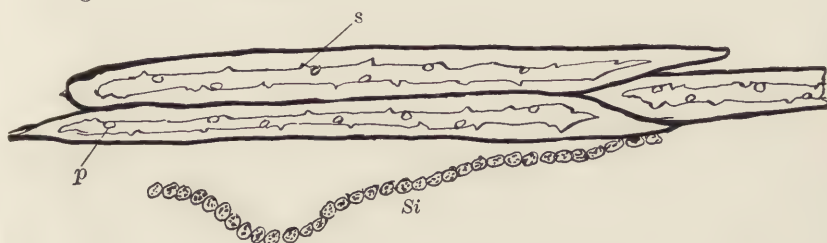


FIG. 52.—Coir Fibre.

s, serrations in wall of lumen; *p*, pores in wall; *si*, silicious skeleton from stegmata.

hanging together in the form of round, silicious skeletons. The cross-section of the fibre is oval in shape and yellowish brown in color, and enclosed in a network of median layers. Coir fibre is employed in the South seas instead of oakum for caulking vessels, and it is claimed that it will never rot. The principal use for coir, however, is for cordage and matting. For cable-making it is said to be superior to all other fibres on account of its lightness and great elasticity. Wright gives the following tests on various cordage:

	Pounds.
Hemp.	190
Coir	224
Bowstring hemp.....	316

CHAPTER XVI.

QUALITATIVE ANALYSIS OF THE TEXTILE FIBRES.

1. IN a commercial examination of manufactured yarns, fabrics, etc., it will only be necessary to distinguish between wool, silk, cotton, linen, jute, hemp, and ramie. Under wool must also be included analogous animal hairs, such as mohair, cashmere, etc. Other animal fibres, such as cow-hair and horsehair, may easily be distinguished even by the naked eye. Of course there are numerous other fibres of vegetable origin which are employed more or less for textile materials, but either they are not liable to occur in conjunction with wool, or they may be readily distinguished from the latter without requiring a special examination.

The best method of distinguishing qualitatively between the various fibres above mentioned is by the use of the microscope, whereby their characteristic physical appearance may be readily observed. Each of the fibres in question presents certain microscopical peculiarities, so that no difficulty is encountered in distinguishing between them. The difference in the microscopical appearance of these fibres may be comparatively observed by reference to the figures given in the preceding pages.

2. **Qualitative Tests.**—A rough physical test to distinguish between animal and vegetable fibres is to burn them in a flame. Vegetable fibres burn very readily and without producing any disagreeable odor; animal fibres, on the other hand, burn with some difficulty and emit a disagreeable empyreumatic odor resembling that of burning feathers. The burnt end of the fibre is also characteristic, vegetable fibres burning off sharply at the end, whereas animal fibres fuse to a rounded, bead-like end.

Tables I and II exhibit the characteristic chemical reactions of the principal fibres, and by suitably employing these tests the various fibres may be easily distinguished from one another.

TABLE I.

Test.	Wool.	Silk.	Linen.	Cotton.
DYESTUFF TESTS.				
Madder tincture.	Nil	Nil	Orange	Yellow
Cochineal tincture.	Scarlet	Scarlet	Violet	Light red
Fuchsin.	Red	Red	Nil	Nil
Acid dyes in general. ...	Dyed	Dyed	Nil	Nil
Mikado yellow.	Nil	Nil	Dyed	Dyed
ACTION OF VARIOUS SALTS.				
Zinc chloride.	Partly diss.	Dissolves	Fibre undiss., yellow color	
Stannic chloride.	Nil	Nil	Black color	
Silver nitrate.	Violet to brown	Nil	Nil	
Mercury nitrate (Millon's)	Red to brown	Nil	Nil	
Cupric or ferric sulphate.	Black	Nil	Nil	
Sodium plumbite.	Black ppt.	No ppt.	Nil	
Ammoniacal copper oxide	Swells only	Nil	Swells and partly dissolves	
Ammoniacal nickel oxide	Undissolved	Dissolves	Undissolved	

The reagents employed for the tests in the tables may be prepared as follows:

(1) *Madder Tincture*.—Extract 1 gm. of ground madder with 50 c.c. of alcohol, and filter from undissolved matter.

(2) *Cochineal Tincture*.—This is made in the same manner as the above, using 1 gm. of ground cochineal insects.

(3) *Fuchsin Solution*.—Dissolve 1 gm. of fuchsin (magenta) in 100 c.c. of water, then add caustic soda solution drop by drop until the fuchsin solution is decolorized; filter and preserve in a well-stoppered bottle. In applying the test with this reagent, the mixed fibres are treated with the hot solution, then well rinsed, when the animal fibres will be dyed red, the vegetable fibres remaining colorless.

(4) *Zinc Chloride Solution*.—Dissolve 1000 gms. of zinc chloride in 850 c.c. of water, and add 40 gms. of zinc oxide, heating until complete solution is effected.

(5) *Stannic Chloride Solution*.—This may be prepared by dissolving 15 gms. of stannous chloride (SnCl_2) in 15 c.c. of concen-

TABLE II.

Test.	Wool.	Silk	Lin.	Cotton.	Hemp.	Jute.
Caustic potash.	Dissolves	Dissolves	Swells up and becomes brown	Swells up and becomes yellowish	Colored	brown
Caustic soda.	Dissolves gradually	Dissolves gradually and becomes reddish	Brown-yellow	Faintly yellow	Brownish	
Ammonia.	—	—	—	—	Unretted, yellow; retted, violet	—
The alkali solution of the fibre treated with: Sodium nitroprusside. Lead acetate. Copper sulphate.	Violet Black Violet then brown	Nil Nil Violet	— — —	— — —	— — —	— — —
Sulphuric acid.	Does not dissolve till heated	Dissolves quickly in hot	Dissolves quickly in cold	Dissolves quickly	Dissolves slowly	Dissolves slowly
Nitric acid.	Yellow, dissolves slowly	Yellow, dissolves quickly	Dissolves without color	No color	Yellow color	—
Chlorin water.	Yellow	Yellow	Bleaches	Bleaches	Yellow-brown	Violet on addition of ammonia
Iodin solution.	—	—	Yellow	Yellow	—	Light brown
Picric acid.	Yellow	Yellow	Nil	Nil	Nil	Nil
Iodin and sulphuric acid.	—	—	Swells, blue	Swells, blue	Swells, green	Swells, yellow to brown
Thymol and sulphuric acid.	—	—	Violet	Violet	—	—
Sugar and sulphuric acid.	Rose-red	Rose-red	—	—	—	—

trated hydrochloric acid, then gradually adding 3 gms. of powdered potassium chlorate (KClO_3). Dilute to 100 c.c. with water.

(6) *Silver Nitrate Solution*.—5 gms. of silver nitrate (AgNO_3) are dissolved in 100 c.c. of water, and preserved in an amber-colored bottle.

(7) *Mercury Nitrate, Millon's Reagent*.—Dissolve 10 gms. of mercury in 25 c.c. of nitric acid diluted with 25 c.c. of water at a luke-warm temperature. Mix this solution with one of 10 gms. of mercury in 20 c.c. of fuming nitric acid.

(8) *Copper Sulphate or Ferric Sulphate*.—Dissolve 5 gms. of these salts respectively in 100 c.c. of water.

(9) *Sodium Plumbite*.—Dissolve 5 gms. of caustic soda in 100 c.c. of water and add 5 gms. of litharge (PbO), and boil until dissolved.

(10) *Ammoniacal Copper Oxide, Schweitzer's Reagent*.—Dissolve 5 gms. of copper sulphate in 100 c.c. of boiling water, add caustic soda solution till the copper compound is completely precipitated, wash the precipitate of copper hydrate well, then dissolve in the least quantity of ammonia water. This gives a deep blue solution.

(11) *Ammoniacal Nickel Oxide*.—Dissolve 5 gms. of nickel sulphate in 100 c.c. of water and add a solution of caustic soda until the nickel hydrate is completely precipitated; wash the precipitate well and dissolve in 25 c.c. of concentrated ammonia and 25 c.c. of water. This solution dissolves silk almost immediately, but reduces the weight of vegetable fibres only about 0.45 per cent., and of wool only 0.33 per cent.

(12) *Caustic Potash or Caustic Soda*.—Dissolve 10 gms. of the caustic alkali in 100 c.c. of water and filter.

(13) *Sodium Nitroprusside*.—Dissolve 2 gms. of the salt in 100 c.c. of water.

(14) *Lead Acetate*.—Dissolve 5 gms. of lead acetate crystals (sugar of lead) in 100 c.c. of water.

(15) *Sulphuric and Nitric Acids*.—The commercial concentrated acids are employed.

(16) *Chlorin Water*.—Water is saturated with chlorin gas

obtained by acting on pyrolusite (MnO_2) with hydrochloric acid. The solution should be preserved in amber-colored bottles.

(17) *Iodin Solution*.—Dissolve 3 gms. of potassium iodide in 60 c.c. of water, and add 1 gm. of iodine. Dilute this solution, before using, with 10 parts of water. When the reaction is employed in connection with sulphuric acid, the latter consists of 3 parts of concentrated sulphuric acid, 1 part of water, and 3 parts of glycerin. The glycerin has the effect of preventing injury to the fibres, and at the same time brings out certain details of the structure when the fibres have previously absorbed the iodine. The fibres are moistened first with the iodine solution and then with the sulphuric acid solution.

(18) *Picric Acid Solution*.—Dissolve 0.5 gm. of picric acid in 100 c.c. of water.

A delicate reaction* for detecting the presence of vegetable fibres in wool is the following: The sample of material under examination is well boiled with water to remove any finishing materials that might be present and interfere with the reaction. Then a small portion of the sample is put in a test-tube with 1 c.c. of water and 2 drops of an alcoholic solution of alpha-naphthol and about 1 c.c. of concentrated sulphuric acid. If vegetable fibres are present they will be dissolved and the liquid will acquire a deep violet color when shaken; the animal fibres only give a yellow to reddish brown coloration but no violet tint. If thymol is used instead of alpha-naphthol, a beautiful red coloration will be produced in the presence of vegetable fibres. Cross and Bevan have devised a delicate test which is serviceable for detecting the presence of vegetable fibres in fabrics: the sample of the cloth is immersed in a solution of ferric chloride and potassium ferrocyanide, when any vegetable fibre present will be colored blue.

Lieberman gives a test to distinguish between animal and vegetable fibres as follows: The fibres are boiled with a solution of magenta which has previously been decolorized by the addition of just sufficient caustic soda; then they are well washed and

* Molisch, *Dingl. Polyt. Jour.*, 1886.

placed in water slightly acidulated with acetic acid. If the fibres are of animal origin they will be colored a deep pink, whereas cotton and linen fibres will be unaffected.

Both this reaction and the one with picric acid (see Table II) are convenient to use when it is desirable to render visible the animal fibres in a mixed yarn or fabric. In case of a mixture of wool and silk fibres, the wool may readily be shown by placing the sample in a very dilute boiling solution of caustic soda containing a few drops of lead acetate solution. Any wool present will be turned brown by this treatment, due to the formation of lead sulphide from the sulphur which forms a constituent of this fibre. Silk (and also cotton or other vegetable fibre) will not be colored. In this test, of course, it will be necessary that the sample is undyed, or, at least, that all coloring-matters originally present be completely removed.

Allen * summarizes in the table on page 214 the reactions to distinguish silk qualitatively from other fibres.

3. Distinction between Cotton and Linen.—As it is often desirable to discriminate between these two fibres, the following tests, as suggested by various authorities, are given:

(1) The fibre is burnt:

Cotton—burnt end tufted.

Linen—burnt end rounded.

(2) The fibre is immersed in concentrated sulphuric acid for two minutes, washed well with water, then with dilute ammonia water, and dried:

Cotton—forms a gelatinous mass soluble in water.

Linen—the fibre is unaltered.

(3) The fibre is treated with an alcoholic solution of madder for fifteen minutes:

Cotton—becomes bright yellow in color.

Linen—becomes dull orange-yellow in color.

(4) The fibre is treated with an alcoholic solution of cochineal for fifteen minutes:

Cotton—becomes bright red in color.

Linen—becomes violet-red in color.

* *Commer. Org. Anal.*, vol. iv. 518.

Test.	Silk, Wool, Fur, or Hair.		Cotton or Linen.
Heated in a small test-tube	Brittle, carbonaceous residue, and odor of burnt feathers. Gases and condensed moisture alkaline to litmus		Charring and smell of burning wood. Gases and condensed moisture acid to litmus
Boiled on a saturated aqueous solution of picric acid and rinsed in water	Dyed yellow		Unchanged
Boiled with Millon's reagent (see p. 210)	Red coloration		No change of color
Treated with cold nitric acid (1.2 sp. gr.)	Colored yellow		No change of color
Moistened with dilute hydrochloric acid and dried at 100° C.	Unchanged		Becomes rotten
Heated to boiling with hydrochloric acid	Silk.	Wool, Fur, or Hair.	Mostly undissolved
	Dissolved	Swells, without at once dissolving	
Boiled with a conc. solution of basic zinc chloride (see p. 208)	Dissolved	Unchanged	Unchanged
Treated with cold Schweitzer's reagent (see p. 210)	Dissolved; not precipitated by addition of salts	Undissolved; dissolves on heating	Dissolved; solution precipitated by addition of salts
Treated in the cold with 10 per cent. caustic soda	Undissolved	Dissolved	Undissolved
Boiled with a 2 per cent. solution of caustic soda	Dissolved; solution not darkened by lead acetate; negative reaction with sodium nitroprusside	Dissolved; solution gives black or brown precipitate with lead acetate and violet color with sodium nitroprusside	Unchanged
Behavior with Molisch's test (see p. 211)	Dissolved, with little coloration	Undissolved, with yellow or brown coloration	Dissolved, with deep violet color

(5) The fibre is immersed in olive oil or glycerin, after previously being well dried:

Cotton—remains opaque and white.

Linen—becomes translucent by reason of the oil rising by capillary action between the individual filaments of the fibres.

(6) The fibre is treated with an alcoholic solution of rosolic acid, and then with a concentrated caustic soda solution:

Cotton—remains colorless.

Linen—becomes rose-red in color.

(7) The fibre is treated with iodine and sulphuric acid solutions (see p. 211):

Cotton—becomes pure blue in color.

Linen—gives only a dull blue color. This test is satisfactory only on unbleached linen.

(8) A small portion of the sample is placed in a solution of equal parts of water and caustic potash; at the end of two minutes the sample is raised with a glass rod and placed between several thicknesses of filter-paper to remove the excess of water:

Cotton—remains white or is a pale, clear yellow in color.

Linen—becomes dark yellow in color. This test is adapted only for white goods.

(9) Kuhlmann recommends the use of a cold concentrated solution of caustic potash. This causes unbleached *cotton* to shrink and curl up, and to become gray or dirty white in color; whereas unbleached *linen* shrinks more than cotton, and acquires a yellowish orange color.

(10) The fibres are immersed in a saturated solution of sugar and common salt, and dried. The separate threads are then ignited:

Cotton—leaves a black-colored ash.

Linen—leaves a gray-colored ash.

4. Distinction between New Zealand Flax (*Phormium tenax*), Jute, Hemp, and Linen.—The following series of tests is recommended to distinguish between the fibres in question:

(1) The material is immersed in chlorin water for one minute, then spread on a porcelain dish, and several drops of ammo-

nia water added. New Zealand flax and jute become at first bright red in color, which afterwards changes to dark brown; linen and hemp acquire a much lighter shade, such as clear brown, orange, or fawn. This method is very good for yarn or unbleached cloth, and is particularly well adapted for testing sail-cloth. French hemp retted in stagnant water is colored a much deeper shade than the same kind of hemp retted in running water; in either case the color is much darker than that acquired by linen. For testing twine this method is said to give excellent results, but in bleached material the difference in the shades produced is not very marked.

(2) To test bleached material, the sample is immersed for one hour, at 36° C., in nitric acid containing nitrous oxide. New Zealand flax assumes a blood-red color, while linen or hemp is tinted pale yellow or rose, according to the method by which it were originally retted.

(3) A sample of the material is heated in concentrated hydrochloric acid. Hemp and linen will not become colored, whereas New Zealand flax becomes yellow at a temperature of 30° to 40° C., then becomes red, brown, and finally black.

(4) A sample of the material is treated with a solution of iodic acid. Hemp and linen are not affected, but New Zealand flax acquires a rose-red color.

(5) Jute is distinguished from New Zealand flax by soaking the fibres for two to three minutes in a solution of iodine, and then rinsing several times in a 1 per cent. solution of sulphuric acid to remove excess of iodine. Jute acquires a characteristic reddish brown color; New Zealand flax becomes clear yellow in color; hemp acquires a light yellow color, and linen a blue color. It will be found best to untwist the separate threads previous to this treatment. For the preparation of the iodine and sulphuric acid solutions, see p. 211.

5. Ligneous Matter (derived from woody tissue) may be detected in admixture with other fibres in the following manner:

(1) On exposing the moistened sample to the action of chlorine or bromine, and then treating it with a neutral solution of sodium sulphite, a purple color will be produced.

(2) If the sample be moistened with an aqueous solution of anilin sulphate, an intense yellow color will be produced.

(3) If the sample be moistened with a solution of phloroglucinol of $\frac{1}{2}$ per cent. strength, and then with hydrochloric acid, an intense violet-red color will be produced. Solutions of resorcinol, orcinol, and pyrocatechol act in a similar manner.

(4) Woody fibre when boiled in a solution of stannic chloride containing a few drops of pyrogallol gives a fine purple color, which is easily seen under a magnifying-glass.

6. Goodale gives the table on page 218, presenting reactions for the principal bast fibres.

7. **Systematic Analysis of Mixed Fibres.**—The table by Pinchon (p. 219) represents an attempt to give a systematic qualitative analysis of the most important textile fibres. With a due degree of caution, this schematic analysis may be employed with considerable success, though confirmatory tests should be applied to the detection of each fibre indicated. The differentiation between the various vegetable fibres given is especially difficult.

8. **Identification of Artificial Silks.**—Hassac gives the table on page 220, presenting systematic tests to identify the different varieties of artificial silks or forms of lustra-cellulose, and also the distinction between these latter and true silk.

9. **Distinction between True Silk and Different Varieties of Wild Silk.**—True silk (from *Bombyx mori*) rapidly dissolves (one-half minute) in boiling concentrated hydrochloric acid; Senegal silk (from *Faidherbia*) dissolves in a somewhat longer time, while yama-mai, tussah, and cynthia silks require a much longer time for complete solution. True silk is also rather easily soluble in strong caustic potash solution, whereas the other varieties of silk are not. The most approved reagent, however, for separating true silk from the wild varieties is a semi-saturated solution of chromic acid, prepared by dissolving chromic acid in cold water to the point of saturation and then adding an equal volume of water. True silk is completely dissolved on boiling in this solution for one minute, whereas wild silk remains insoluble.

Under the microscope true silk can readily be told from wild silks, as the latter fibres are broad and flat, and show very dis-

REACTIONS OF BAST FIBRES.

Name of Fibre.	Reaction with Schweitzer's Reagent.	Reaction with Iodin and Sulphuric Acid.	Reaction with Anilin Sulphate.	Length of Raw Fibre, cm.	Width, mm.	Length of Bast-cells, mm.	Width of Bast-cells.	
							Limit mm.	Average mm.
Raw flax	Soon attacked and almost entirely dissolved	Colored blue	Remains uncolored	20-140	.04-.62	20-40	.012-.076	.015
Raw hemp	Clean fibre dissolved	Greenish blue to pure blue	Faint yellow	100-300	—	10	.015-.028	.016
Raw jute	Bluish color; more or less distinct swelling	Yellow to brown	Golden yellow to orange	150-300	.03-.14	.8-4.1	.010-.021	.016
Raw esparto	Bright green	Rusty red	Egg-yellow	10-40	.09-.50	.5-1.9	.009-.015	—
Raw aloë	Bluish color; feeble swelling	Reddish brown	Golden yellow	40-50	.075-.105	1.3-3.7	.015-.024	—
New Zealand flax	Bluish color; more or less swelling	Varies, with purity of fibre, yellow, green, or blue	Uncolored	80-110	.042-.12	2.5-5.6	.008-.019	.013
China grass	When "cottonized," quickly acted upon, and almost completely dissolved	Copper-red to blue	Uncolored	—	—	220	.040-.080	.050
Ramie	do.	do.	do.	—	—	80	.016-.126	—
Coir	Perceptible swelling; blue color	Reagent not applicable on account of color of fibre	Not applicable	15-33	.05-.30	.4-.96	.012-.020	.016
Agave	Swells and becomes somewhat blue	With iodine sol., yellow; on addition of H_2SO_4 , brown	Yellow	100	.10-.46	1.02-2.22	.016-.021	.017
Manila	Blue color and feeble swelling	With iodine sol., yellow	Pale yellow	750	.010-.08	2.0-2.7	.012-.046	.029

TABLE FOR ANALYSIS OF MIXED FIBRES (PINCHON).

The mixture is boiled with 10% KOH for 20 minutes.

Part dissolves		Part remains undissolved		The whole dissolves	
Another sample is boiled 5 minutes with zinc chloride solution					
The whole dissolves	Part dissolves	None dissolves	None dissolves	Part dissolves	None dissolves
The alkaline solution does not blacken on the addition of lead acetate: <i>Silk</i>	The dissolved portion is not blackened by lead acetate, but the insoluble portion does: <i>Silk</i> and <i>Wool</i>	The mass is blackened by lead acetate: <i>Wool</i>	Chlorin water (or ammonia) colors the fibre	On addition of lead acetate is	Nitric acid colors portion yellow, the residue remaining white: <i>Flax, Cotton</i>
			Red-brown	Blackened	Not blackened
			The fibre is colored red by fuming nitric acid: <i>New Zealand Flax</i>	Caustic potash partly dissolves the fibres insoluble in zinc chloride; the remaining fibres are soluble in ammoniacal copper oxide: <i>Wool, Silk, and Cotton</i>	Picric acid colors portion yellow, the residue remaining white: <i>Silk, Cotton</i>
			Alcoholic fuchsin colors the fibre	No yellow color with caustic potash: <i>Cotton</i>	
			Permanently		
			Caustic potash stains yellow	No yellow color with caustic potash: <i>Cotton</i>	
			Iodin and sulphuric acid color		
			Yellow <i>Hemp</i> Blue <i>Flax</i>		

IDENTIFICATION OF ARTIFICIAL SILKS.

Reagent	Natural Silk.	Collodion Silk.	Cellulose Silk.	Gelatin Silk.
Water	No change	Swell up; addition of alcohol or glycerin causes contraction again		
Conc. sulphuric acid	—	Swells rapidly and dissolves	Gradually becomes thinner and dissolves	Only dissolves on heating
Acetic acid	—	Slight swelling	Slight swelling	Dissolves on boiling
Half-saturated sol. of chromic acid	Dissolves slowly	Dissolves in the cold		
Diphenylamin and sulphuric acid	—	Blue color	—	—
Caustic potash, 40%	Dissolves without color	Swell without dissolving, but color liquid yellow		Dissolves rapidly
Ammoniacal copper solution	—	Swells quickly and dissolves	Swells slowly and dissolves	Insoluble; colors liquid violet
Alkaline copper glycerin solution	Dissolves immediately at 80° C. tussah silk dissolves in one minute on boiling	Unchanged	Unchanged	Dissolves on boiling
Iodin in potassium iodide	—	An intense red color which disappears on washing		
Iodin and sulphuric acid	Yellow	Deep violet-blue	Pure blue	Yellowish to reddish brown
Iodin in zinc chloride	Becomes yellow and disintegrates	Blue-violet	Gray-blue to gray-violet	Becomes yellow and disintegrates
Ignition	Odor of burnt feathers	No odor	No odor	Odor of burnt feathers

tinct longitudinal striations, which are absent in true silk. Exception must perhaps be made with the wild silk from *Saturnia spini*, which can scarcely be told from true silk by a microscopical examination. With regard to distinguishing between the different varieties of wild silks themselves, some valuable information may be gained by a determination of their relative diameters. Höhnelt gives the following values for the greatest thickness of the different silks:

True silk	(<i>Bombyx mori</i>)	20 to 25 μ
Senegal silk	(<i>Faidherbia bauhinia</i>)	30 to 35 μ
Ailanthus silk	(<i>Attacus cynthia</i>)	40 to 50 μ
Yama-mai silk	(<i>Antheraea yama-mai</i>)	40 to 50 μ
Tussah silk	(<i>Bombyx selene</i>)	50 to 55 μ
Tussah silk	(<i>Bombyx mylitta</i>)	60 to 65 μ

According to Wiesner and Prash, the breadths of the single fibres of different silks are as follows:

Ailanthus silk	7 to 27, mostly 14 μ
Yama-mai silk	10 to 45, mostly 23 μ
<i>Bombyx mylitta</i>	14 to 75, mostly 42 μ
<i>Bombyx selene</i>	27 to 41, mostly 34 μ
Senegal silk	12 to 34, mostly 22 μ
True silk	9 to 21, mostly 13 μ

True silk, ailanthus silk, and Senegal silk do not show any cross-marks, or only very faint indications of such; whereas with tussah silk and yama-mai silk the cross-marks are very distinct and characteristic.

The microscopical appearance of the end of the fibre on being torn apart also serves at times as a useful means of distinguishing the variety of silk; true silk, tussah silk, and yama-mai silk show scarcely any fraying at the ends; in Senegal silk the fraying is very noticeable in almost every fibre; while in ailanthus silk about one-half of the number of fibres show a frayed end.*

* Besides the wild silks mentioned above, there are a few others of lesser importance, which for the sake of completeness are herewith described:

1. *Saturnia polyphemus*, a North American variety; consists of very flat fibres, with large air-canals and numerous structural filaments separating at the edge of the fibre; coarse lumps of adhering sericin are frequent; well-defined

By the use of the polariscopic attachment to the microscope, considerable differences can be observed in the interference colors displayed by the different varieties of silks. It is best to conduct these observations under a magnification of 30 to 50 diameters; and as the silk fibres are more or less ovoid in section, it must be borne in mind that the same fibre will give a different color phenomenon, depending on whether it is viewed from the narrow side or from the broad side. Hence, to obtain trustworthy results, the appearance of the same side only of the fibres should be compared. Also, the appearance of single fibres only, and not of crossed fibres, should be taken. Höhnel gives the following description of the appearance of the different silk fibres viewed in polarized light, the observations being made with a dark field, and under a magnification of 30 to 50 diameters:

1. *True silk*: (a) *broad side*, very lustrous, of a bluish or yel

cross-marks are also frequent. The single fibre is about $33\ \mu$ in width; in its polariscopic appearance these fibres very much resemble *ailanthus* silk.

2. *Arryndia ricini*; the fibres are even more flattened than the preceding, and resemble a thin band or ribbon; large air-canals are of frequent occurrence; striations very apparent; the sericin layer is in places very thin, and sometimes apparently lacking altogether. The double fibre is about 45 to $55\ \mu$ in width, and 4 to $6\ \mu$ thick. At the edge of the fibre frayed ends of structural filaments are often apparent. Cross-marks are rather ill-defined, but of frequent occurrence. The sericin layer, though thin, is quite uniformly developed.

3. *Antheræa pernyi* has a very flat fibre, resembling a ribbon; it does not fray out at the ends, and shows scarcely any single filaments. The double fibre measures 60 to $80\ \mu$ in width and 8 to $10\ \mu$ in thickness. Cross-marks are rather few and indistinct. The sericin layer is very thin, and in general hardly noticeable. Moderately sized air-canals are present.

4. *Saturnia cecropia* occurs in Texas. The fibre is also flat and ribbon-like in form; the double fibre measures 60 to $90\ \mu$ in width and 10 to $15\ \mu$ in thickness; air-canals are frequent and large, hence the fibre usually appears rather dark under the microscope. The cross-marks are very distinct, and at such points the fibre is much broader. The fibre is usually much frayed out and individual filaments are easily distinguished. The sericin layer is quite thin but very uniform.

5. *Attacus lunula* has fibres which are not so flat as the preceding. The double fibre is 25 to $35\ \mu$ in width and 12 to $18\ \mu$ in thickness. The air-canals are fine and delicate; and the fibre shows but a slight degree of fraying. The sericin layer is very thin and finely granulated on the surface; in places, it has the form of irregular shreds. The fibre as a whole has a brownish yellow appearance due to the ochre-yellow color of the sericin layer.

lowish opalescent white; the same color is nearly always to be found over the entire breadth; (b) *narrow side*, exactly similar to the preceding.

2. *Yama-mai silk*: (a) *broad side*, generally of a pure bluish opalescent white; also darker bluish to almost black tones; nearly all of the colors are brilliant; (b) *narrow side*, shows all colors, very brilliant and contrasted; darker and blackish tones also occur.

3. *Tussah silk* (from *Bombyx selene*): (a) *broad side*, shows all colors, very brilliant; thickness of the fibre very uneven, hence the colors change through the length; the thick parts are dark blue and reddish violet, while the thinner parts are yellow or orange; (b) *narrow side*, shows bright red and bright green colors, though often but slightly visible; the colors form long flecks; often only dark gray to black.

4. *Tussah silk* (from *Bombyx mylitta*): (a) *broad side*, a bluish opalescent white prevailing; also brown, gray, and black tones; the colors occur in flecks like preceding, though scarcely ever dark blue, but mostly bright orange to red or brown; (b) *narrow side*, color a dull gray with bright red or green flecks; the general appearance is very similar to the preceding silk.

5. *Ailanthus silk*: (a) *broad side*, bright yellow or yellow-brown to gray-brown colors; (b) *narrow side*, nearly all colors, but rather soft and not very contrasted, seldom very bright, but rather dull; short flecks of green, yellow, violet, red, or blue.

6. *Senegal silk*: (a) *broad side*, bright yellowish white, gray to brown, seldom bluish white in color; (b) *narrow side*, faint and dull gray, brown, to blackish colors, seldom bright colors.

10. The following micro-analytical tables are given by Höhnel for the qualitative determination of vegetable fibres:

I. TABLE FOR THOSE VEGETABLE FIBRES BOTANICALLY
DESIGNATED AS HAIR STRUCTURES.

1. (a) Each single fibre consists of a single cell. (see 4).

(b) Each fibre consists of two cells, namely, a short, thick, underlying cell, and an overlying pointed, principal cell. The

fibres are grayish brown, scarcely 0.5 cm. long; hard, woolly, lifeless, thin-walled, but round-stapled. Such fibres form the thick upper coating on the leaves of the *Cycadæ macrozamia* of New South Wales, and are used as vegetable wool in upholstery.

(c) Each single fibre consists of a series of cells, hence is a cellular fibre. The cells are golden yellow to brown in color, generally clinging together, and empty. The fibre as a whole is highly lustrous, but very harsh and brittle; very thin-walled, flat, and ribbon-shaped; frequently twisted on its axis; broad, and 0.5 to 2 cms. long. Such fibres form the thick coating on the leaves of various ferns (*Cibotium*) in Asia, Australia, and Chili. The material is used for upholstery under the name of *pulu*.

(d) Each fibre consists of numerous cells growing side by side, or of several series of such; forms the so-called tuft. (see 2).

2. (a) Hairs straight, stiff; white to dirty yellow in color. . (see 3).

(b) Hairs woolly, tough, brownish violet in color, 4 to 6 mm. long; consisting of long cotton-like, flat, twisted, spiral cells, the walls of which are frequently thick and undulating; the contents of the cells moderately abundant, yellow to violet, and in part colored red with hydrochloric acid. This fibre covers the small, egg-shaped, flattened fruit of the new Holland composite *Cryptostemma calendulaceum*. It is used in Australia as a stuffing material.

(c) Hairs woolly, harsh, reddish yellow in color; the cells are very thin-walled, colorless, and generally empty; in places, however, filled with a homogeneous reddish-yellow substance; where two cells come together side by side there are to be noticed round spots. The individual cells are relatively broad, extremely varied, and irregularly thick; irregularly bent in places and frequently knitted together. This fibre forms the coating of a plant (*Hibiscus*?) growing in Cuba; as employed for upholstery materials it goes by the name of *Majagua*.

3. (a) The hairs are 1 to 3 cm. long, and on the average are under 50 μ wide; they consist of two layers of cells which grow into one another. The inner walls are rough; the outer walls are thin and indented, hence lie close against the inner portion; the section walls are quite noticeable and thick; the tufts end in 2 to

6 pointed, often hook-shaped cells; the end cells show numerous pores; weakly lignified. This fibre consists of the ripe fruit spicula of cotton-grass, *Eriophorum angustifolium*, *E. latifolium*, etc..... Cotton-grass (see Fig. 53).

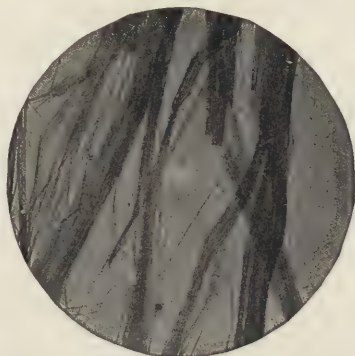


FIG. 53.—Fibres of Cotton-grass or Vegetable Silk ($\times 50$).
The sharp fractures show the brittle nature of the fibres.

(b) The fibres are 5 mm. long; mean breadth of the tufts 8 to 16 μ , the widest being under 30 μ ; the tufts do not end with sharp-pointed cells; the section-walls under low magnification appear as little knots and are usually quite noticeable. This fibre is obtained from the small, lance-like fruit of the reed mace, *Typha angustifolia*, which grows on a small shaft, and carries the hairs on the other end. It is used for upholstery and other filling material.....*Reed-mace hair* (see Fig. 54).

4. (a) The fibres are flat, woolly, frequently twisted in a spiral manner on their axes; not lignified.....(see 5).

(b) The fibre is generally cylindrical, stiff, not twisted; somewhat lignified, hence colored red with indophenol or phloroglucol.....(see 6).

5. (a) Fibres 1 to 5 cm. long; white to yellowish brown; 12 to 42 μ thick.....*Cotton* (see Fig. 55).

(b) Fibres only 9.5 cm. long; very thin; usually consisting of tufts; violet-brown in color. See above under 2 (b).

Cryptostemma hairs.

6. (a) The product consists of grassy spicula with a hairy covering; the hairs are 5 to 8 mm. long and about 10 to 15 μ wide;

the thickness of the wall of the thick, cylindrical-pointed hairs remains rather uniform up to the point itself, hence the latter appears very thick; spots are often observed. This fibre is upholstery material from *Saccharum officinale* *Sugar-cane hairs*.

(b) The product consists of short white fibres, about 8 to 24 μ in width, and of oval, flat fruit-shells, 4 mm. wide and 5 mm. long; the hairs are broadened at the base, hence generally knife-shaped; thick-walled, with transverse, fissure-like marks; the upper portion of the hair is very thin and rough-walled; colorless; the ends are usually blunt and contain a granular matter; slightly lignified, especially at the base.

Poplar cotton.

(c) The product consists entirely of hairs and is almost entirely free from accidental impurities *Vegetable down and silk*.

7. (a) The fibres have two to five longitudinal ridges on the walls, which are either crescent-shaped or quite flat, running into network at the base; these ridges are broad and difficult to discern in a surface view of the fibre, yet sometimes very apparent; the maximum thickness about 35 μ ; white or yellowish in color. These fibres are the seed-

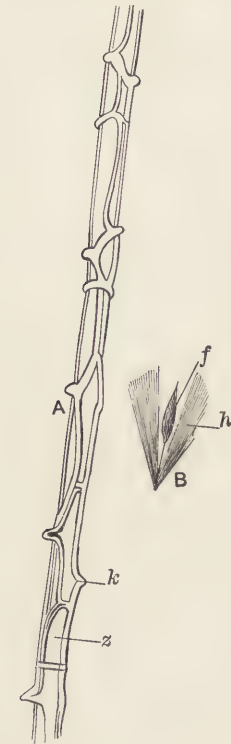


FIG. 54.—Reed-mace Hair. (Höhncl.)
B, ripe fruit at *f*; *h*, hair around fruit; A, portion of hair; *z*, cells; *k*, knotted structure.

hairs of *Apocynen* and *Asclepiadeen*. *Vegetable silk* (see Fig. 56).

(b) The fibres are without ridges; transverse ridges frequently at the base or as a network. Maximum thickness generally under 35 μ ; yellowish to brown. These fibres consist of the hairs which cover the fruit-pods of *Bombacæ*.

Vegetable down (Fig. 59; see 13).

8. (a) The hairs are 3.5 to 4.5 cm. long, and the largest are 50 to 60 μ in diameter. (see 9).

(b) The fibres are 1.5 to 4 cm. long, and the largest are 35 to 45 μ in diameter (see 10).

9. (a) The fibres are narrowed at the base, and directly above are strongly swollen, and up to 100 μ in thickness; numerous

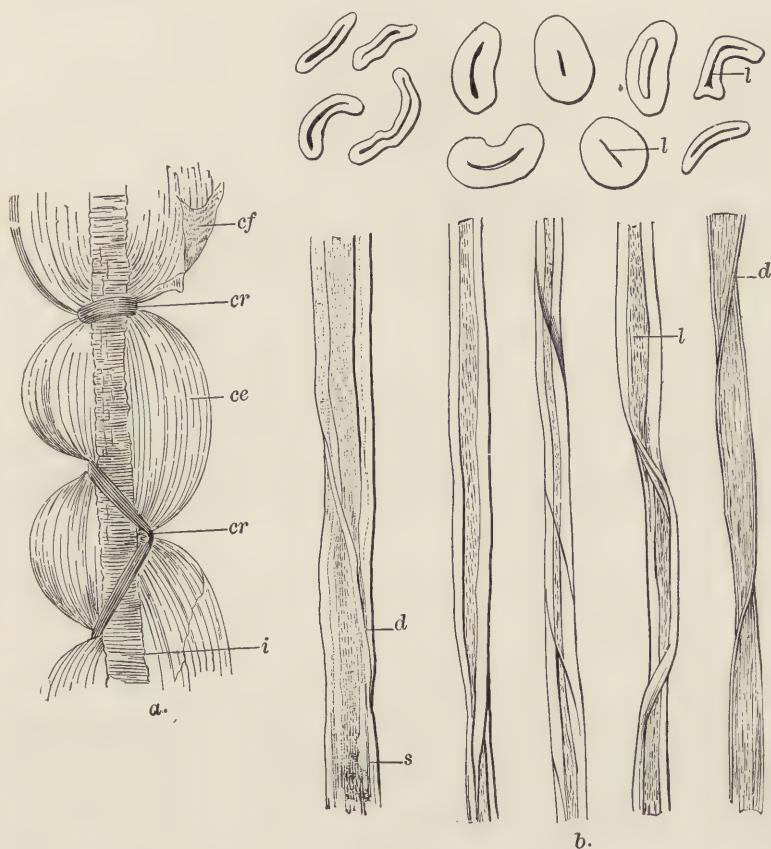


FIG. 55.—Cotton Fibres. (Höhncl.)

a, portion swollen with Schweitzer's reagent; *cf*, shreds of cuticle; *cr*, rings of cuticle; *ce*, cellulose; *i*, dried protoplasmic canal; *b*, various cotton fibres with sections above; *l*, lumen; *d*, twists; *s*, granulations on cuticle.

pores at the base; the fibres grow brush-like on a stem, are yellowish and harsh. This is vegetable silk from Senegal.

Strophantus (see Fig. 56).

(b) The fibres are white, firm, and tough, not harsh; form a hairy tuft or crown. This is vegetable silk from India.

Beaumontia grandiflora (see Fig. 57).

(c) Yellow rod fibres, weak, stiff, straight, and harsh.

Calotropis procera, Senegal.

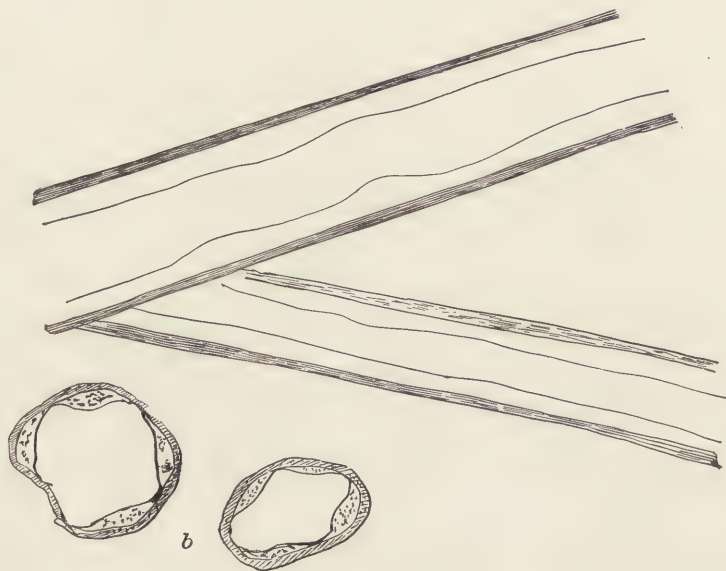


FIG. 56.—Fibre of *Strophantus*.
a, longitudinal view; b, cross-sections.

10. (a) At the base of the hair there are spots or pores . . . (see 11).

(b) Spots or pores lacking. Vegetable silk from *Asclepias cornutii*, *curassavica*, etc. . . . (see Fig. 58).

11. (a) Spots large; round or oblique; the walls of the fibre are not thicker at the base than at the upper portion; the ridges on the fibre are remarkably well developed, the hairs are strongly bent back at the base. Vegetable silk from *Calotropis gigantea*.

(b) Spots small, no longitudinal markings; walls thicker than the foregoing fibre; ridges less noticeable and often apparently lacking. . . . (see 12).

12. (a) Hairs narrowed at the base. . . . *Hoya viridiflora*.

- (b) Hairs not narrowed at all, or scarcely so. *Marsdenia*.
 13. (a) The hairs have mesh-like ridges at the base, situated obliquely, or have spiral ridges. (see 14).

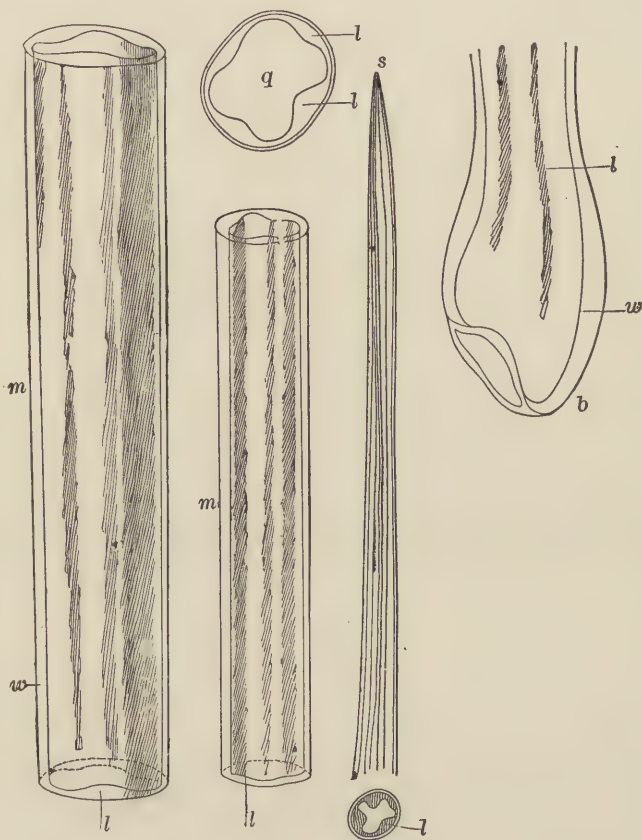


FIG. 57.—Vegetable Silk from *Beaumontia grandiflora*. (Höhnel.)
 b, base of fibre; s, pointed ends; q, cross-section; m, middle portion of fibre;
 w, cell-wall; l, longitudinal ridges.

- (b) Without mesh-like ridges at the base. (see 15).
 14. (a) Base broader, thin-walled, with oblique, mesh-like ridges or spiral swellings, which often extend to a considerable distance. Points very thin-walled, gradually tapering, not ended sharply; frequently containing a reddish-brown homogeneous

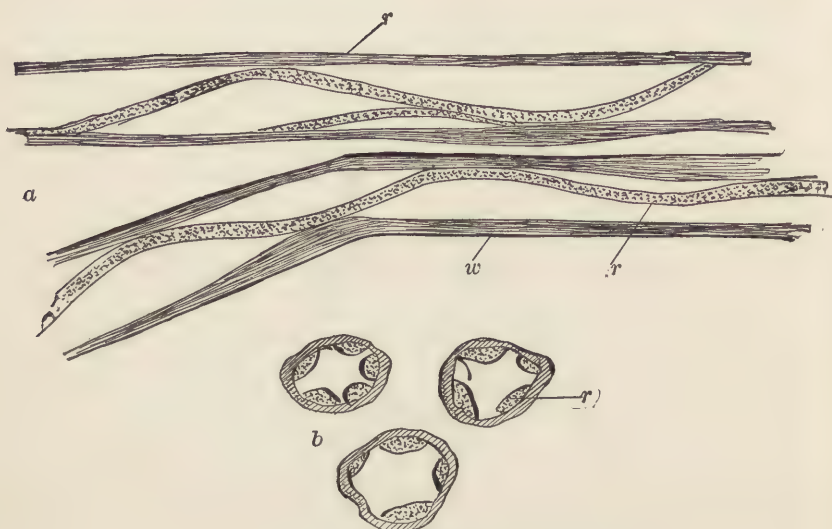


FIG. 58.—Vegetable Silk from *Asclepias cornutii*.
a, longitudinal view; *b*, cross-sections; *r*, thickened ridges; *w*, cell-wall.

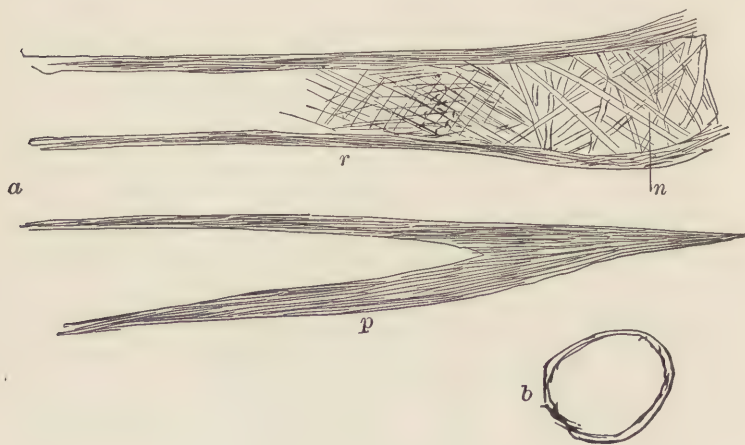


FIG. 59.—Ceiba Cotton.
a, longitudinal views; *r*, base of fibre, showing network at *n*; *p*, pointed end;
b, cross-section, showing cell-walls.

granular substance; fibre not very stiff, usually notched. Base contains no marrow. *Vegetable down from Eriodendron anfractuosum.*

(b) Quite similar, but the ends are not so tapering; without marrow; whole fibre somewhat rough-walled. *Vegetable down from Bombax heptaphyllum.*

(c) Very similar to (a), but walls of fibre are quite roughened, and contain at intervals throughout its length a granular marrow; base thick-walled, mesh-like fibrous ridges, but neither spirally developed nor very broad—at most only one-sixth of the width of the fibre; ends, as before, thick-walled. *Vegetable down, Ceiba cotton, from Bombax ceiba*.....(see Fig. 59).

15. (a) Raw fibre, brown, rough-walled; walls 1 to 7 μ thick; not indented; points without marrow; stiff and very sharp at end; base not broadened, often contains granular matter. *Vegetable down from Ochroma lagopus.*

(see Fig. 60).

(b) Raw fibre, yellowish, thin-walled, walls very uneven in thickness; frequently weakly developed longitudinal ridges; just at the base the wall is very thick. *Vegetable down from Cochlospermum gossypium.*

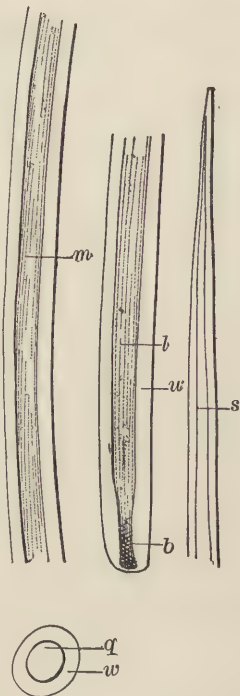


FIG. 60.—*Ochroma lagopus* (Höhncl.)

m, middle part of fibre; *b*, base; *s*, pointed end; *l*, lumen; *q*, cross-section; *w*, cell-wall.

II. GENERAL TABLE FOR THE DETERMINATION OF THE VEGETABLE FIBRES.

Including cotton, as well as the more important fibres derived from bast or sclerenchymous tissues.

A. Fibres Colored Blue, Violet, or Greenish with Iodin and Sulphuric Acid.

(a) BAST FIBRES AND COTTON. (Cotton, flax, hemp, sunn hemp, ramie, Roa fibre.)

I. The cross-sections become blue or violet with iodine and sulphuric acid; show no yellowish median layer; the lumen is often filled with a yellowish marrow.

1. *Cross-sections*: they occur either singly or in small groups; the single sections do not join over one another; are polygonal, and have sharp edges; iodine and sulphuric acid colors them blue or violet; they show closely packed, delicate layers; the lumen appears as a yellow point.

Longitudinal appearance: with iodine and sulphuric acid, quite blue; it appears transparent, quite uniformly thick; smooth or delicately marked; joints frequent; indications of dark lines running through, which are usually crossed; enlargements on the fibre, especially at the joints, frequent; the lumen appears as a narrow yellow line; the natural ends of the fibres are sharply pointed; length 4 to 66 mm., thickness 15 to 37 μ .

Linen or Flax (see Fig. 68).

2. *Cross-sections* single or very few in a group, loosely held together; polygonal or irregular, mostly flat, very large; colored blue or violet with iodine and sulphuric acid; stratification not noticeable; the lumen is large and irregular; frequently filled with a dark yellow marrow; radial fissures frequently apparent.

Longitudinal appearance: many of the fibres remarkably broad; the width of a single fibre very uneven; smooth or striped; very often ruptures in the wall; with iodine and sulphuric acid, blue or violet; the lumen readily seen; very broad, often containing a dark yellow marrow; joints noticeable; dark, transverse lines frequent, often crossing each other; the ends are relatively

thick-walled and blunt; length 60 to 250 mm., thickness up to 80 μ *China grass, Ramie* (see Fig. 42).

3. *Cross-sections*: not many in the groups; polygonal; mostly with straight or slightly curved sides and blunt angles; the lumen is contracted lengthwise regularly; frequently contains a yellow marrow, many sections are surrounded by a thin, greenish-colored layer; not closely joined to one another. The sections often show very beautiful radial marks or fissures and concentric layers; the various layers are colored differently.

Longitudinal appearance, as with China grass; proportional dimensions similar. *Roa fibre* (see Fig. 61).



FIG. 61.—Section of Roa Fibre.
f, fissures in inner wall.

4. *Cross-sections* always isolated, rounded, various shapes, mostly kidney-shaped; with iodine and sulphuric acid, blue or violet; lumen contracted, line-shaped, often containing a yellowish marrow; no stratification.

Longitudinal appearance: fibres always separate; with iodine and sulphuric acid, a fine blue; streaked and twisted; lumen broad, distinct, frequently contains yellowish marrow; ends blunt; the entire fibre not soluble in concentrated sulphuric acid; coated with a very thin cuticle; length 10 to 60 mm., breadth 12 to 42 μ *Cotton* (see Fig. 55).

II. Cross-section blue or violet with iodine and sulphuric acid; polyhedral, rounded or irregular; always surrounded by a yellow median layer.

1. *Cross-sections* always in groups, with angles more or less rounded off, lying very close to one another; all of them sur-

rounded by a thin, yellowish median layer; the lumen is line-shaped, single or forked, often broad, with inturning edges, without marrow; good concentric stratification; the different strata being differently colored.

Longitudinal appearance: with iodine and sulphuric acid, blue, greenish, or dirty yellow; fibres irregular in thickness, frequently with appended portions of yellowish median layer; joints and transverse lines frequent; stripes very distinct; the lumen is not very apparent, but broader than linen; ends are broad, thick-walled, and blunt, often branched; length 5 to 55 mm., breadth 16 to 50 μ *Hemp* (see Fig. 62).

2. *Cross-sections* in large groups, lying very close together and touching; very similar to those of hemp; often crescent-shaped. Polygonal or oval, with lumen of varying size, frequently containing yellowish marrow; lumen usually not line-shaped, but irregular; a broad yellow median layer always present, from which the blue inner strata are easily distinguished; stratification very distinct, as with hemp.

Longitudinal appearance: as with hemp, except in dimensions, which are: length 4 to 12 mm., breadth 25 to 50 μ .

Sunn hemp (see Fig. 47).

(b) LEAF FIBRES. (With vascular tissue; without jointed structure. Esparto and Pineapple fibre.)

1. *Cross-sections* in large, compact, often crescent-shaped groups; very small; pale blue or violet with iodine and sulphuric acid; surrounded by a thick, shell-like network of median layer; rounded or polygonal; lumen like a point or streak; thick cuttings appear greenish or even yellow; frequently bundles of vascular tissue with one or two rows of thick, yellow-colored fibres.

Longitudinal appearance: Fibres slender, regular, very thick-walled, smooth; lumen often invisible, generally as a fine line; ends are tapered with needle-like points; color with iodine and sulphuric acid, blue, often but slightly pronounced; frequently present short, thick, stiff, completely lignified fibres from vascular tissue; length 5 mm., breadth 6 μ .

Pineapple fibre.

2. *Cross-sections* in groups; with iodine and sulphuric acid,

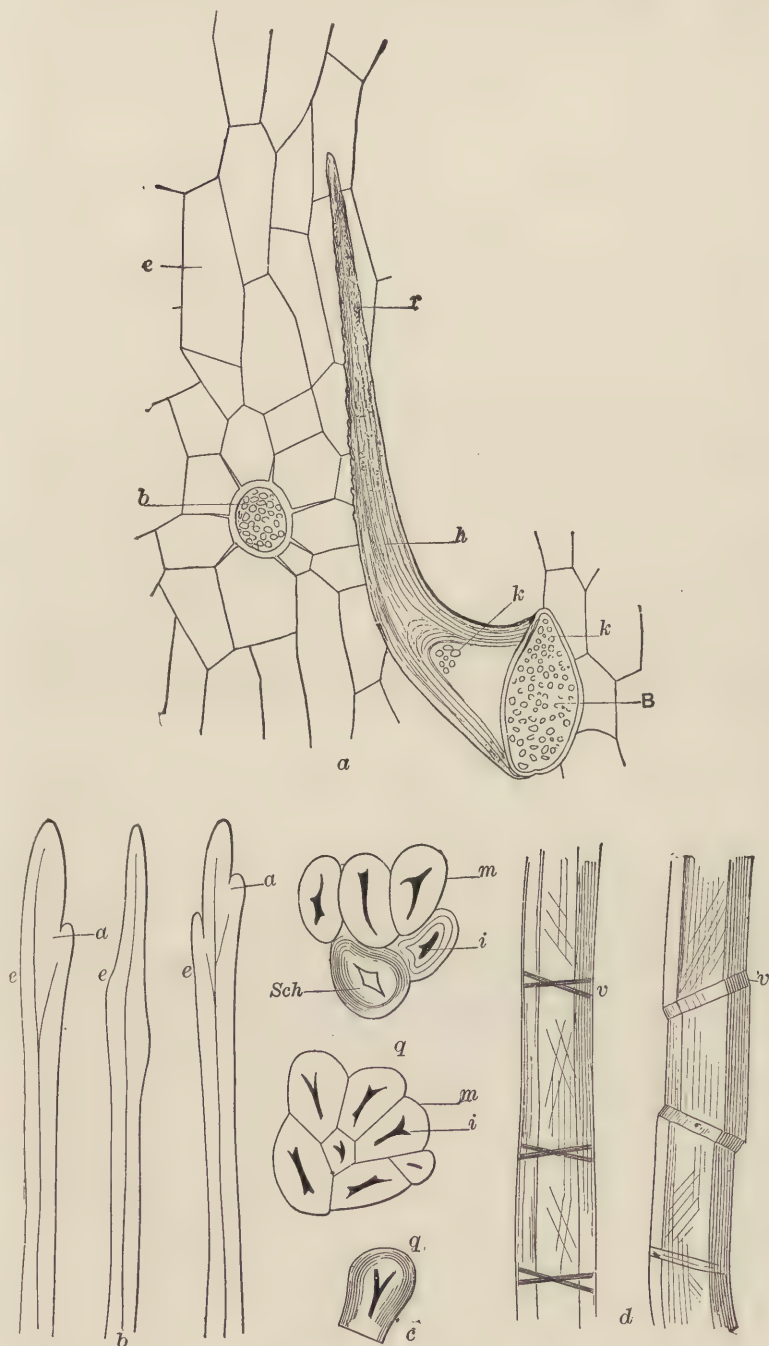


FIG. 62.—Hemp. (Höhncl.)

a, epidermis of hemp; *b*, ends of fibres; *c*, cross-section; *d*, longitudinal view.

mostly blue, though also yellow; often with pronounced stratification; the outer strata frequently yellow, while the inner are blue; rounded or oval, seldom straight-sided; lumen like a point.

Longitudinal appearance: the fibres are short; blue with iodine and sulphuric acid; thin, very firm, smooth, uniform in breadth; lumen yellow, line-shaped; ends are seldom pointed, mostly blunt or chiselled off, or forked; length 1.5 mm., breadth 12 μ *Esparto* (see Fig. 63).

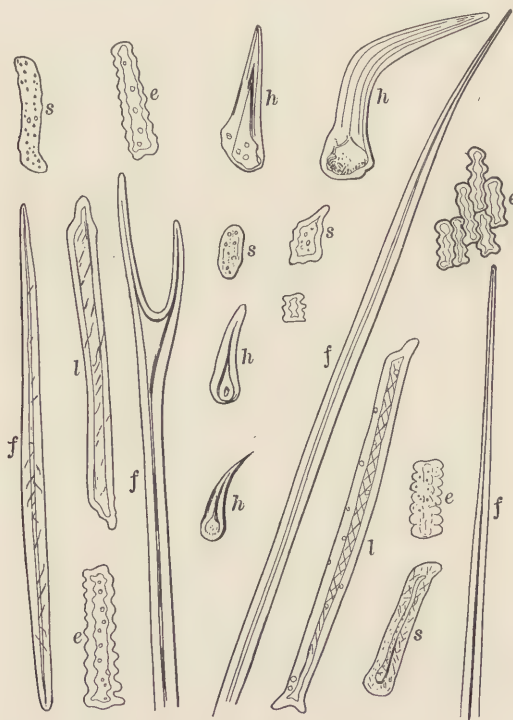


FIG. 63.—Esparto-grass. (Höhncl.)

s, short sclerenchymous elements; l, cells; f, fibres; h, hairs; e, epidermal cells.

B. Fibres which are Colored Yellow with Iodin and Sulphuric Acid.

(a) DICOTYLEDONOUS FIBRES. (Without vascular bundles; lumen showing remarkable contractions. Including Jute, *Abel-*

moschus, Gambo hemp, *Urena*, and Manila hemp; the latter sometimes shows vascular tissue.)

I. Cross-sections in groups; polygonal and straight-lined, with sharp angles; lumen round or oval, smooth, and without marrow; cross-sections with narrow median layers showing the same color as the inner strata with iodine and sulphuric acid; lengthwise appearance shows the lumen with contractions.

1. *Cross-sections* polygonal, straight-lined; lumen, in general, large, round, or oval.

Longitudinal appearance: fibres smooth, without joints or stripes; lumen distinctly visible; broad; with contractions; the ends always blunt and moderately thick; ends have wide lumen; length 1.5 to 5 mm., breadth 20 to 25 μ *Jute* (see Fig. 40).

2. *Cross-sections* in general somewhat smaller than jute; sides straight, with sharp angles; lumen frequently like a point or line, oval, occasionally pointed; not so large as with jute.

Longitudinal appearance: fibres quite even in thickness, smooth, with occasional joints or stripes; lumen narrow, irregular in thickness, contractions frequent; the ends are broad, blunt, frequently thickened; length 1 to 1.6 mm., breadth 8 to 20 μ *Pseudo-jute* or *Musk mallow* of *Abelmoschus*.

II. Cross-sections in groups, lying close together; polygonal, with sharp lines and sharp or rounded angles; lumen without marrow; the median layer is broad, and with iodine and sulphuric acid is colored perceptibly darker than the inner layer of cell-wall; the lumen in places is completely lacking.

1. *Cross-sections* more or less polygonal, with sharp or slightly rounded angles; the lumen is small, becoming broader and more oval as the section is more rounded; the median layer is broad, and is colored considerably darker than the cell-wall with iodine and sulphuric acid; stratification occasional and indistinct.

Longitudinal appearance: the fibres vary much in thickness; lumen generally narrow, with decided contractions, and in some parts totally absent; the broader fibres often striped; ends are blunt and generally thickened; length 2 to 6 mm., breadth 14 to 33 μ *Gambo hemp* (see Fig. 48).

2. *Cross-sections* always in groups; small, polygonal, with

sharp angles; lumen very small, appearing as a point or a short line.

Longitudinal appearance: occasionally jointed or striped; lumen with decided contractions, in some places altogether lacking; ends blunt and sometimes thickened; length 1.1 to 3.2 mm., breadth 9 to 24 μ .

Pseudo-jute from Urena sinuata (see Fig. 64).

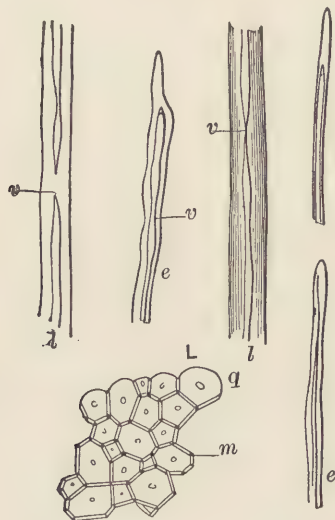


FIG. 64.—Pseudo-jute. (Höhnel.)

l, longitudinal view; *v*, interruption of lumen; *e*, end with thick wall; *g*, cross-section; *m*, median layer; *L*, small lumen.

(b) MONOCOTYLEDONOUS FIBRES. (Occurring as vascular bundles together with bast; the lumen exhibits no contractions; in Manila hemp vascular bundles often lacking. Includes New Zealand flax, Manila hemp, *Sansevieria* or bowstring hemp, Pita hemp, and Yucca fibre.)

I. Cross-sections generally rounded, occasionally polygonal; the lumen is always rounded, without contractions longitudinally; median layer indistinct, or only as a narrow line; vascular tissue small in amount, or altogether lacking.

1. *Cross-sections* small, generally rounded, lying loosely sepa-

rated; very rounded angles; lumen small, round or oval, without marrow.

Longitudinal appearance: the fibres are stiff and thin; the lumen is small but very distinct, and uniform in width; the ends are pointed; no markings and no joints; length 5 to 15 mm., breadth 10 to 20 μ *New Zealand flax* (see Fig. 49).

2. *Cross-sections* polygonal, with rounded angles, in loosely adherent groups; lumen large and round, often containing yellow marrow.

Longitudinal appearance: fibres uniform in diameter; walls thinner than those of *New Zealand flax*; lumen large and distinct; ends pointed or slightly rounded; silicious stigmata adhering to the fibre-bundles and to be found in the ash as bead-like strings, insoluble in hydrochloric acid; length 3 to 12 mm., diameter 16 to 32 μ *Manila hemp* (see Fig. 50).

II. *Cross-sections* polygonal; lumen large and polygonal, with angles quite sharp; median layer lacking or only in the form of a thin line.

1. *Cross-sections* distinctly polygonal, often with blunt angles, lying compactly together; lumen large and polygonal, with sharp angles; no stratification in cell-wall.

Longitudinal appearance: fibres thin and smooth; lumen large and distinct; ends pointed; length 1.5 to 6 mm., diameter 15 to 26 μ *Sansevieria fibre*.

2. *Cross-sections* polygonal, not many sections to a group, but lying compactly together; angles slightly rounded; lumen not very large, polygonal, often having blunt angles; besides the bast fibre sections are to be noticed some vascular bundles in the form of large spirals.

Longitudinal appearance: fibres uniform in diameter; lumen not very large, but uniform; no structure; ends pointed and sometimes blunt; length 1.3 to 3.7 mm., diameter 15 to 24 μ .

Aloe hemp (see Fig. 51).

3. *Cross-sections* polygonal, with straight lines; angles sharp, though sometimes blunt; sections lie compactly together; lumen large and polygonal, though angles not so sharp.

Longitudinal appearance: fibres stiff, and often very wide

towards the middle; lumen large; ends broad, thickened, and often forked; large, shining crystals to be found in the ash, which are derived from the chisel-shaped crystals of calcium oxalate clinging to the outside of the fibre; these crystals are often $\frac{1}{2}$ mm. in length; length of fibre 1 to 4 mm., diameter 20 to 32 μ .

Pita hemp (see Fig. 65).

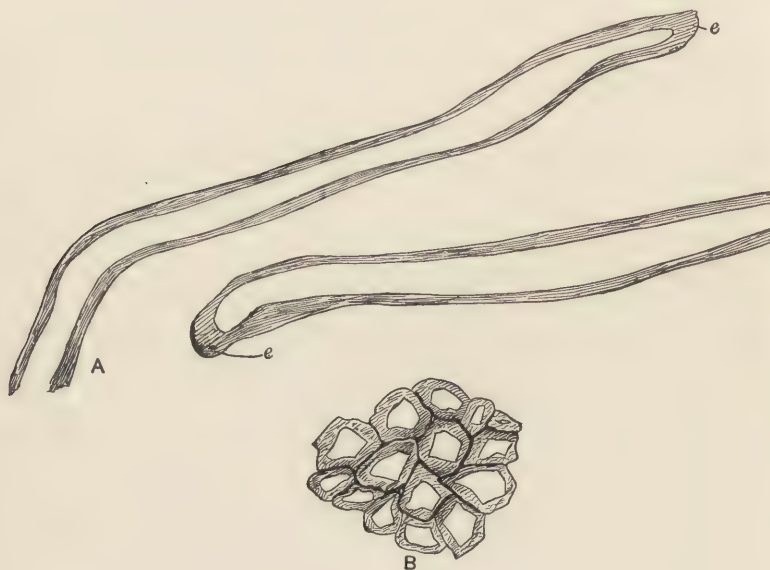


FIG. 65.—Pita Hemp (*Agave americana*).
A, longitudinal section; B, cross-section; e, blunt ends.

III. Cross-sections polygonal and small, sides straight, with very sharp angles; lumen small, usually as a point or line-shaped; sections lie compactly together and are surrounded by a thick, distinct median layer.

1. *Cross-sections* as above.

Longitudinal appearance; fibres very narrow; lumen also very narrow; longitudinal ridges frequent; ends usually sharp-pointed; length 0.5 to 6 mm., diameter 10 to 29 μ .

Yucca fibre (see Fig. 66).

C. Analytical Review of the Chief Vegetable Fibres.

1. Those occurring as thick, fibrous bundles, also with vascular tissue (monocotyledonous fibres).....(see 2).

Vascular tissue absent; sections and fibres always single; round or kidney-shaped by being pressed together; fibres with a thin external cuticle insoluble in concentrated sulphuric acid, and not swelling (vegetable hairs).....(see 7).

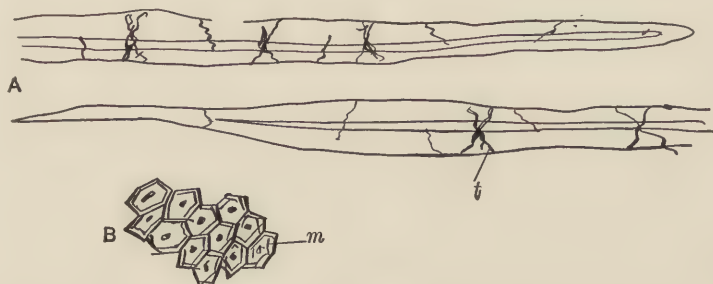


FIG. 66.—Yucca Fibre.

A, longitudinal view; B, cross-section; *m*, median layer; *t*, transverse markings.

Vascular tissue absent; the fibres are bundles of bast filaments; sections occurring two or more together (mostly true dicotyledonous fibres).....(see 13).

2. Lumen very narrow, line-shaped, much thinner than the wall.....(see 3).

Lumen in thickest fibres almost as wide, or even wider, than the wall; completely lignified.....(see 4).

3. Sections polygonal, sides straight, with sharp angles; completely lignified; diameter 10 to 20 μ ... *Yucca fibre* (see Fig. 66).

Sections rounded to polygonal; often flattened or egg-shaped; the inner strata at least not lignified; diameter 4 to 8 μ .

Pineapple fibre.

4. Thick, strongly silicified stegmata occurring at intervals on the fibre-bundles in short to long rows, sometimes but few; these are four-cornered, have serrated edges, and show a round, bright, transparent place in the middle; they are easily seen after the fibre has been macerated with chromic acid, and are about 30 μ in length; in the ash of fibres previously treated with nitric acid,

they appear in the form of pearly strings, often quite long, and insoluble in hydrochloric acid; they are joined together lengthwise; the fibres are thick-walled, with fissure-like pores; 3 to 12 mm. long; the fibre-bundles are yellowish and lustrous.

Manila hemp (see Fig. 48).

Stegmata present, sometimes in small, sometimes in large quantities; they are lens-shaped, small (about 15 μ wide), and are fastened to the exterior fibres of the bundles by serrated edges; in the ash of the fibre they melt together in the form of indistinct globules; in the ash of fibres previously boiled in nitric acid they appear as yeast-cells, joined together in round skeletons of silica; the fibres are often thin-walled, with numerous pores; 1 to 2 mm. in length; the raw fibres generally brown and rough. *Coir*.

Stegmata absent, hence the fibres are not accompanied by silicified elements. (see 5).

5. Fibre-bundles covered externally at intervals with crystals of calcium oxalate, at times up to 0.5 mm. in length; lustrous, with quadrangular sections, chisel-shaped at the ends, hence they appear as thick, needle-shaped crystals; when present in large numbers these crystals occur in long rows which are frequently visible to the naked eye, and always easily recognizable under the microscope, especially in the ash. The fibre-bundles are mostly thick, and their outer fibres (as a result of their preparation) frequently contain fissures or are torn; thickness of the walls very uneven; fibres often much widened at the middle.

Pita hemp (see Fig. 65).

Without crystals, generally thin; in cross-section usually less than 100 fibres to a bundle; thickness of walls and lumen very uniform. (see 6).

6. Sections mostly round, not very compact; lumen usually thinner than the wall, but never a single line; in section round or oval; vascular tissue in but small amount.

New Zealand flax (see Fig. 49).

Sections, on one side at least, polygonal; section of lumen polygonal, with angles more or less sharp; generally as wide or wider than the wall; vascular tissue frequent.

Aloe hemp (see Fig. 51).

7. Fibres mostly rope-shaped, twisted, externally streaked, generally possessing fine granules or marked with little lines, therefore rough; thin to thick walls; cross-sections squeezed together, or round to kidney-shaped, hence the fibre has more or less the shape of a flat band; section of lumen more or less arched, line-shaped, frequently containing yellow marrow; consists of pure cellulose with the exception of the thin cuticle.

Cotton (see Fig. 55).

Fibres not twisted, smooth externally, and without longitudinal markings; fibres not flat, sections round; walls generally very thin; sometimes, however, they are thick; lignified, scarcely swelling in ammoniacal copper oxide. . . . *Vegetable down* } (see 8).
Vegetable silks }

8. Fibres on the inside possess from 2 to 5 broad ridges, which at times are very noticeable, at others scarcely visible; they run lengthwise in the fibre, and in section are semicircular; on this account the walls appear unequal in thickness when viewed longitudinally; the maximum thickness is about 35 μ .

Vegetable silks (see 9).

Fibres without ridges; maximum thickness mostly 30 to 35 μ *Vegetable down* (see 12).

9. Largest diameters 50 to 60 μ ; length 3.5 to 4.5 cm.. (see 10).

Largest diameters 35 to 45 μ ; length 1.5 to 4 cm.. (see 11).

10. Fibres contracted at the lower end, and directly above abruptly swelling, becoming 80 μ thick; the under portion of the swollen area contains numerous pore-canals; fibres feather-like or brush-like, arising from a straight shaft.

Vegetable silk from Senegal.

Contrary to the above the fibres originate from one point, like a fan; remarkably strong, curved backwards; very firm.

Vegetable silk from India.

Like the foregoing, but the fibre is stiff, straight, weak, and brittle. *Calotropis procera.*

11. Thickened ridges very noticeable; in the cross-sections often occurring in the form of a semicircle; bound together in a strictly reticulated manner.

Vegetable silk from Asclepias cornuti.

Thickened ridges indistinct, projecting but slightly in the cross-section. *Vegetable silk from Asclepias curassavica*.

12. Raw fibre, yellowish; broadened at the lower end (up to 50 μ); also reticular thickening or transverse markings; wall 1 to 2 μ thick. *Bombax cotton* (Fig. 59)

Raw fibre, brown; the lower end contracted and not showing reticulated thickenings; fibre almost altogether thin-walled, though just at the lower end very thick-walled.

Cochlospermum gossypium.

13. Thick fibre-bundles, whose outer surface contains at intervals series of thick silicious plates, having sharp indented edges and a round, hollow space. *Manila hemp* (see under 4).

Silicious plates absent; lengthwise the lumen often exhibits remarkable contractions, while the wall is very uneven in thickness; at intervals, indeed, the lumen is almost entirely interrupted; joints and transverse fissures along the fibre; transverse markings and lines, which appear somewhat like zones or knots, are completely lacking, or are very rare and indistinct; completely lignified, hence colored yellow with iodine and sulphuric acid. (see 14).

Silicious plates absent, also remarkable contractions of the lumen; thickness of the walls very uniform; joints and fissures along the fibre, transverse lines and markings frequent, hence the fibre often appears as if it contains swollen knots; unlignified, or only lignified on the external layer of membrane, hence lengthwise the fibre is colored blue with iodine and sulphuric acid or violet or green, or at the most colored yellow in places. . . (see 17).

14. Exterior layers of membrane narrow and showing the same coloration with iodine and sulphuric acid as the inner layers, hence the same as the entire cross-section; the lumen hardly ever completely interrupted. (see 15).

Median layer in sections wide; colored considerably darker with iodine and sulphuric acid; lumen often completely interrupted. (see 16).

15. Lumen in general large, diameter as wide or only a little narrower than the wall; in section round or oval, seldom as a point; no crystals of calcium oxalate. . . . *True jute* (see Fig. 40).

Lumen usually small, diameter much narrower than the thick wall in section frequently as a point; crystals of calcium oxalate of frequent occurrence (detected by ignition).

Pseudo-jute (Abelmoschus) (see Fig. 67).

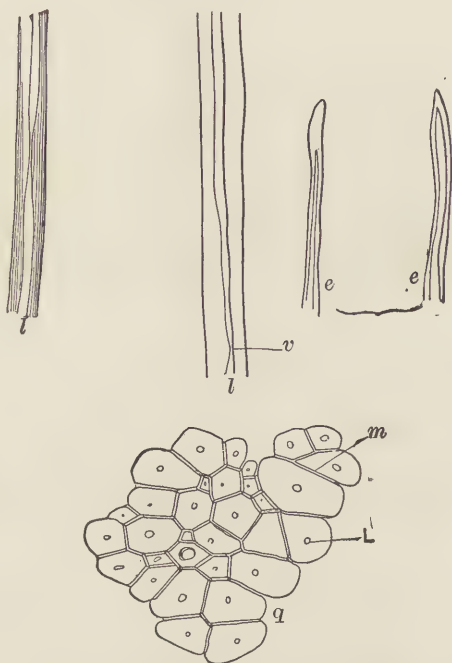


FIG. 67.—*Abelmoschus* Jute. (Höhnel.)

l, longitudinal view; *q*, cross-section; *e*, ends; *L*, small lumen; *v*, narrowing of lumen.

16. Lumen almost always considerably smaller than the wall; ends usually very thick-walled and narrow; calcium oxalate crystals of frequent occurrence.

Pseudo-jute (Urena sinuata) (see Fig. 64).

Lumen frequently as wide as or wider than the wall, mostly narrower however; ends broad and blunt. *Gambo hemp* (see Fig. 48).

17. The lumen in the middle portion of the fibre generally line-shaped, much narrower than the wall; ends never blunt, always sharply pointed; sections isolated or in small groups, regular in diameter, sharp-angled and straight-sided polygonals;

without separate median layer; iodine and sulphuric acid colors the entire section blue or violet; the lumen in the cross-section is very small, or as a point, containing a marrow which is colored yellow with iodine and sulphuric acid. . *Linen or Flax* (see Fig. 68).

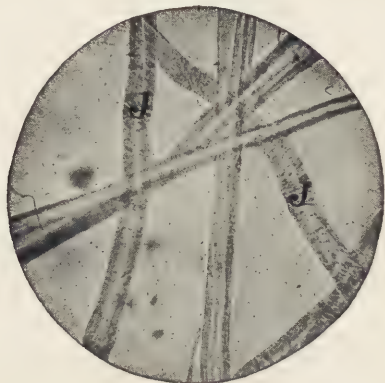


FIG. 68.—Linen Fibre.

Showing jointed structure or knot-like formation at *J*.

Lumen, at least in the central portion of the fibre, always much thicker than the walls; in section generally more or less flattened, narrow to broad, egg-shaped or oval. Fibre ends blunt, never sharply pointed; sections almost never sharp-angled polygonals, but more or less oval or elliptical, and with a rounded boundary..... (see 18).

18. Breadth of fibre up to $80\ \mu$; maximum length 15 to 60 mm.; sections always in compact groups, which often consist of many fibres, with thinner or thicker layers of membrane which are colored yellow with iodine and sulphuric acid, hence the fibre is never colored a pure blue, but dirty blue to greenish, and in places yellow; ends often have side branches projecting. (see 19).

19. Lignified exterior membranes very thin; lumen in section narrow, very seldom broad, fissure-like or line-shaped, often branched, without marrow..... *Hemp* (see Fig. 62).

Lignified exterior layers often as wide as the interior layers, or wider; the interior layers are often loosened in places from the exterior ones where they are thin; lumen in section scarcely ever narrow or fissure-shaped, but broad, oval, or long; often containing a yellowish marrow..... *Sunn hemp* (see Fig. 47).

CHAPTER XVII.

QUANTITATIVE ANALYSIS OF THE TEXTILE FIBRES.

1. Wool and Cotton Fabrics.—The finishing materials and coloring-matters should be removed as far as possible by boiling the sample to be examined first in a 1 per cent. solution of hydrochloric acid, then in a dilute solution of sodium carbonate (about a one-twentieth per cent. solution), and finally in water. A portion of the material is then dried at 100° C. for an hour (or until constant weight is obtained) and weighed; this weight will represent the actual amount of true fibre present in the sample, and the loss will correspond to moisture. Then steep for twelve hours in a 20 per cent. solution of sulphuric acid, and mix with three volumes of alcohol and water; filter off the dissolved cotton and wash the residue of wool well with alcohol. Dry at 100° C., and weigh; this will give the amount of wool present. The following example will illustrate this method:

	Grams.
Sample weighed.	3.62
After treatment with acid and alkali.	3.17
Finishing materials, etc.	<u>0.45</u>
After drying at 100° C.	2.77
Loss as water.	<u>0.40</u>
Wool left after treating with acid.	1.96
Cotton, by difference.	<u>0.81</u>

Hence the composition of this sample would be as follows:

	Per Cent.
Finishing materials.	12.43
Moisture.	11.05
Wool.	54.14
Cotton.	<u>22.38</u>
	100.00

Another, and perhaps a better, method for determining the relative amounts of wool and cotton in a mixed fabric or yarn, especially when the cotton is present in rather large proportion, is to remove the wool by treatment with a dilute boiling solution of caustic potash. The estimation is carried out in the following manner:

The sample to be tested is treated with hydrochloric acid and sodium carbonate solutions as before, in order to remove finishing materials, and after thorough washing is dried at 100° C. and weighed. This gives the weight of the dry fibres. The weighed sample is then boiled for twenty minutes in a 5 per cent. solution of caustic potash.* The residue is well washed in fresh water, and redried at 100° C. and weighed. The residue consists of cotton, the wool having been dissolved by the caustic potash.† If the residue becomes disintegrated and cannot be washed and dried as one piece, it should be collected on a tared filter (one which has been dried at 100° C. and weighed) and well washed with water, then dried at 100° C. and weighed. The tared weight of the filter subtracted from the latter will give the weight of the cotton particles.

Examples :

(a) Analysis of a cloth sample:

	Grams.
Weight of sample.....	5.42
After treatment with acid and alkali.....	5.10
Finishing materials, etc.	<u>0.32</u>
After drying at 100° C.	4.26
Loss as water.	<u>0.84</u>
Cotton left after boiling with caustic alkali.....	2.82
Wool, by difference.	<u>1.44</u>

* It is not advisable to use caustic soda instead of caustic potash, as the results obtained are not as satisfactory.

† In case yarns are to be analyzed, the preliminary treatment should consist of a thorough scouring with soap. After drying in the air, the loss in weight should be recorded as grease and miscellaneous dirt. On then drying at 100° C. to constant weight, the loss will represent moisture, and the residue dry fibre. This is then analyzed as in the manner above described.

Hence the composition of this sample would be:

	Per Cent.
Finishing materials.	5.98
Moisture.	15.50
Cotton.	52.03
Wool.	26.49
	<hr/>
	100.00

Since the cotton itself suffers a slight loss on boiling with caustic potash, it is customary, as a correction, to add to the cotton found 5 per cent. of its weight, and to subtract a corresponding amount from that of the wool. On applying this correction the result of the above analysis would become:

	Per Cent.
Finishing materials.	5.98
Moisture.	15.50
Cotton.	54.63
Wool.	23.89
	<hr/>
	100.00

Figured on the weight of the dry fibre, the relative amounts of the two fibres in the above samples would be:

	Per Cent.
Cotton.	69.5
Wool.	30.5
	<hr/>
	100.00

Since, however, in making mixes, the dry weights of the fibres are not taken, we may assume the weight to include the normal amount of moisture held by each fibre. As the normal amount of moisture for cotton is about 8 per cent., and for wool about 16 per cent., we may approximate very closely to the true composition of this sample by adding to the dry weights of the fibres their respective amounts of moisture; the relative amounts of cotton and wool then become:

	Grams.
Weight of cotton found.	2.82
Add 5 per cent. correction.	0.14
	<hr/>
	2.96

This represents 92 per cent. of air-dry cotton.

Hence air-dry cotton would be.	3.22
	<hr/>
Weight of wool found.	1.44
Subtract correction for cotton.	0.14
	<hr/>
	1.30

This represents 84 per cent. of air-dry wool.

Hence air-dry wool would be..... 1.54

Therefore the relative amounts of cotton and wool on this basis would be:

	Per Cent.
Cotton.....	65.8
Wool.....	34.2

(b) Analysis of a yarn:

	Grams.
Weight of sample.....	5.65
Scoured in soap, washed, and air-dried.....	4.97
Grease, etc.....	0.68
Dried at 100° C.....	4.32
Loss as moisture.....	0.65
Weight of filter-paper dried at 100° C.....	1.16
Weight of filter and residue of cotton dried at 100° C.....	3.66
Weight of dry cotton.....	2.50
Add 5 per cent. correction.....	2.62
Correct for moisture at 8 per cent.....	2.85
Weight of dry wool by difference (with correction).....	1.70
Correct for moisture at 16 per cent.....	2.02

Hence the composition of this yarn may be expressed as:

	Per Cent.
Grease, etc.....	12.00
Moisture.....	11.50
Cotton.....	44.25
Wool.....	32.25
	100.00

And the relative proportion of the two fibres would be as follows:

	Dry at 100° C.	Air-dry.
Cotton.....	60.7	58.5
Wool.....	39.3	41.5
		100.00

When a rough, approximate analysis of a wool-cotton is desired, it will be sufficient only to weigh the sample, boil for fifteen minutes in a 5 per cent. solution of caustic potash, wash well in acidulated water, then in fresh water, and dry in the air. On reweighing, the amount of cotton will be ascertained, while

the loss in weight will represent the amount of wool. Results attained by this process are usually sufficiently accurate to give one a practical idea of the approximate relative amounts of wool and cotton present in a sample of mixed goods.

Another method for the separation of wool from cotton in their quantitative estimation is treatment of the mixed fibres with an ammoniacal solution of copper oxide, whereby the cotton is dissolved; and after washing and drying, the residue of wool is weighed. This method, however, is not very satisfactory, as it is difficult, in the first place, to obtain a complete and thorough solution of the cotton; and in the second place, the wool will be considerably affected by this treatment and more or less decomposed. Consequently the results obtained by this method are not very accurate, and it cannot be recommended.

2. Wool and Silk.—Silk is soluble in boiling hydrochloric acid, whereas wool is not soluble in this reagent to any extent. Hence this method may be utilized for the quantitative estimation of the two fibres when occurring together. The sample is first treated with acid and alkali in the manner already described in order to remove foreign materials other than actual fibre. It is then dried and weighed; then boiled in concentrated hydrochloric acid for fifteen minutes. The residue is collected, washed thoroughly, dried again, and weighed. The loss in weight represents silk, while the weight of the residue represents wool. Another method, and one which is perhaps more satisfactory, is to dissolve the silk by treatment with an ammoniacal solution of nickel oxide, in which reagent the silk is very readily soluble even in the cold. It only requires a treatment of about two minutes to completely dissolve the silk in most silk fabrics other than plush. Richardson* found that by this treatment cotton lost only 0.45 per cent. in weight and wool only 0.33 per cent. As silk in plush goods and similar fabrics is much more difficult to dissolve, it is recommended to boil such material with the nickel solution for ten minutes under a reflux condenser. By this treatment cotton will lose only 0.8 per cent. in weight. The nickel solution is best prepared by dissolving 25 grams of crystallized

* *Jour. Soc. Chem. Ind.*, XII, 430.

nickel sulphate in 80 c.c. of water; add 36 c.c. of a 20 per cent. solution of caustic soda, carefully neutralizing any excess of alkali with dilute sulphuric acid. The precipitate of nickel hydroxide is then dissolved in 125 c.c. of strong ammonia, and the solution diluted to 250 c.c. with water. Instead of the above reagent, a boiling solution of basic zinc chloride may be employed for the purpose of dissolving the silk. This latter solution is obtained by heating together 1000 parts of zinc chloride, 850 parts of water, and 40 parts of zinc oxide until complete solution is effected. Richardson recommends that the sample to be examined should be plunged two or three times into the boiling solution of zinc chloride, care being taken that the total time of immersion does not exceed one minute. The zinc chloride solution should be sufficiently basic and concentrated in order to obtain good results. Under the best conditions, cotton loses about 0.5 per cent. in weight, and wool from 1.5 to 2.0 per cent.

3. Silk and Cotton.—The methods given above for separating silk from wool may also be used for the separation and quantitative determination of silk in fabrics containing this fibre in conjunction with cotton.

Another method for separating silk from cotton is by the use of an alkaline solution of copper and glycerin, which serves as an excellent solvent for the silk. The reagent is prepared as follows: Dissolve 16 grams of copper sulphate in 150 c.c. of water, with the addition of 10 grams of glycerin; then gradually add a solution of caustic soda until the precipitate of copper hydrate which is at first formed just redissolves. This solution readily dissolves silk, but is said not to affect either wool or the vegetable fibres. Richardson, however, has found that cotton heated with this solution for twenty minutes (the time necessary to dissolve silk in plush) lost from 1 to 1.5 per cent. in weight and became friable and dusty on drying; while woollen fabrics lost from 9 to 16 per cent. in weight. Hence the reagent would be useless in the analysis of fabrics containing wool.

4. Wool, Cotton, and Silk.—Samples of shoddy frequently contain all three of these fibres present in greater or lesser amount, and often it is desirable to know at least the approx-

imate amounts of each fibre in the mixture. A method of procedure recommended is the following: A weighed sample of the material is boiled for thirty minutes in a 3 per cent. solution of hydrochloric acid, washed, and then boiled for thirty minutes in a 0.1 per cent. solution of soda-ash. This preliminary operation is similar to that above described in the preceding analyses, and is for the purpose of freeing the fibres as far as possible from extraneous foreign matter. After thorough washing and air-drying, the weight of the sample is again taken, and the loss will represent *miscellaneous foreign matter*. The sample is then dried at 100° C. to constant weight; the loss in weight will represent *moisture*. The sample is then divided into two weighed portions; the first is treated for five minutes with a boiling solution of basic zinc chloride prepared as above described, washed thoroughly with acidulated water, then with fresh water, and dried at 100° C. again. The loss in weight will represent the amount of silk present. The second portion of the sample is boiled for ten minutes in a 5 per cent. solution of caustic potash; washed thoroughly, dried at 100° C. and weighed. This weight, with a correction of 5 per cent. added to it, will represent the amount of cotton present. The amount of wool is obtained by taking the difference between the total weight of the combined fibres and the sum of the weights of the silk and cotton.

Example:

	Grams.
Sample of loose shoddy weighed.	5.06
Treated with acid and alkali, and air-dried.	4.23
Loss as foreign matter.	<u>0.83</u>
Dried at 100° C.	3.62
Loss as moisture.	<u>0.61</u>

Divided into two portions:

	Grams.
(a) weighed.	1.95
(b) weighed.	1.67
(a) treated with zinc chloride.	1.73
Loss as silk.	<u>0.22</u>
(b) treated with caustic potash, residue as cotton.	0.34
Loss as wool.	<u>1.33</u>

Hence the composition of this sample on the basis of dry fibre would be:

	Per Cent.
Silk.....	11.3
Cotton.....	21.5
Wool.....	67.2
	<hr/> 100.0

Von Remont gives the following method for analyzing fabrics containing a mixture of silk, wool, and cotton. Four quantities (*A, B, C, D*) of 2 grams each of the air-dried material are weighed out. Portion *A* is kept aside, and each of the other three is boiled for fifteen minutes in 200 c.c. of water containing 3 per cent. of hydrochloric acid. The liquid is decanted, and the boiling repeated with more dilute acid. This treatment removes the size and the major portion of the coloring-matter. Cotton is nearly always decolorized quite rapidly, wool not so readily, and silk but imperfectly, especially with black-dyed fabrics. The samples should be well washed and squeezed in order to remove the acid liquor. Portion *B* is set aside. Portions *C* and *D* are then placed for two minutes in a boiling solution of basic zinc chloride (of 1.72 sp. gr., and prepared as above described), which dissolves any silk present. They are then washed with water containing 1 per cent. of hydrochloric acid, and again with pure water, until the washings no longer show the presence of zinc. Portion *C* is squeezed and set aside. Portion *D* is boiled gently for fifteen minutes with 60–80 c.c. of caustic soda solution (1.02 sp. gr.) in order to remove any wool. The sample is then carefully washed with water. The four portions are next dried for an hour at 100° C., and then left exposed to the air for ten hours in order to allow them to absorb the normal amount of hygroscopic moisture. The four samples are then weighed, and calling *a, b, c*, and *d* their respective weights, we shall have

$a - b$ = dye and finishing material;

$b - c$ = silk;

$c - d$ = wool;

d = cotton (or vegetable fibre).

This method is open to objections, as the plan of using air-

dried material, then drying at 100° C., and subsequently exposing to the air again before reweighing, is liable to give very erroneous results. Richardson recommends that the samples should be thoroughly dried at 100° C. before being weighed out, and the treated portions should subsequently be dried at the same temperature before weighing. In order to prevent the sample from absorbing moisture during weighing, it is best to use a weighing-bottle for holding the dried fibre. The sample before drying is placed in a weighing-bottle (the weight of which has been ascertained previously) and heated in an air-oven at 100° C. for the time specified, during which the cover of the weighing-bottle is removed. After the drying process is completed the stopper is replaced in the weighing-bottle; the latter is taken from the oven, allowed to cool, and is then weighed. The difference between this weight and the weight of the empty bottle will give the amount of dry fibre.

Treatment with a boiling solution of 3 per cent. hydrochloric acid for the purpose of removing finishing materials is rather too severe, as the acid will act on the wool and the cotton, sometimes causing considerable error. Boiling with a 1 per cent. solution of acid for ten minutes is to be preferred.

The following is given as a practical method to determine if shoddy contains cotton and silk fibres: Boil 10 grams of the shoddy to be tested for one hour in 400 c.c. of water containing 0.8 gram of alum, 0.3 gram of tartar, 1 c.c. of hydrochloric acid, 0.1 gram of chrome, and 0.05 gram of blue-stone. Rinse and dye with 0.3 gram of logwood extract. Rinse and dry. The undyed fibres are then picked out and examined; cotton will remain white, while silk will be colored a dingy red.

The analysis of heavy pile fabrics containing a mixture of fibres is especially difficult unless the fabric is disintegrated. In the analysis of plush for the amount of silk present, Richardson suggests treating the sample with a boiling solution of basic zinc chloride in the manner previously described; but when silk is to be determined in light fabrics (especially in the presence of wool), it is best to treat the sample for one to three minutes with a cold solution of ammoniacal nickel oxide. He gives the following

comparison of results in the analysis of a sample of plush, using the three different methods for dissolving the silk:

	By Solution of Ammoniacal Nickel Oxide.	By Solution of Basic Zinc Chloride.	By Copper- glycerin Reagent.
Moisture and finish.....	11.34	11.00	10.04
Silk.....	45.60	45.00	47.06
Cotton.....	43.60	44.00	42.90

Samples of plush with hard cotton backs may best be analyzed by successive treatment with acid and copper-glycerin reagent. On other cotton material, however, this method is not suitable; nor is it to be used in the presence of wool, as this fibre is considerably dissolved by the copper-glycerin reagent.

The following table by Richardson shows a comparison of the three methods employed for dissolving silk:

Fibre.	Actually Present.	Percentage Obtained by		
		Ammoniacal Nickel Oxide.	Basic Zinc Chloride.	Copper-glycerin Reagent.
Silk.....	5.84	5.92	5.52	18.80
Wool.....	76.31	76.58	80.08	64.05
Cotton.....	17.85	17.50	14.40	17.15

The ammoniacal nickel oxide solution appears to give the best result; hence in analyzing a sample containing silk, wool, and cotton, it is best to first remove the silk by means of this reagent. The insoluble residue left after this treatment is boiled with a 1 per cent. solution of hydrochloric acid, washed well in fresh water, and then boiled for five to ten minutes in a 2 per cent. solution of caustic soda, which is sufficient to completely remove the wool without materially affecting the cotton.

Allen* also recommends the ammoniacal nickel solution for use in dissolving silk from a mixture of fibres. His method of analyzing a textile sample is as follows: The yarn or fabric is cut

* *Commer. Org. Anal.*, vol. IV. 523.

up very fine with a pair of scissors, and thoroughly dried at 100° C. One gram of the material thus prepared is treated with 40 c.c. of the cold ammoniacal nickel oxide solution for two minutes. The liquid is then filtered, and the residue, consisting of wool and cotton, is digested for two or three minutes in a boiling solution of 1 per cent. hydrochloric acid. It is then washed free from acid, dried at 100° C., and weighed. To separate the wool from the cotton the residue is boiled with about 50 c.c. of a 1 per cent. solution of caustic potash for ten minutes, and the solution filtered. The residue, consisting of cotton, is washed free from alkali, dried at 100° C., and weighed.

To remove gum and weighting materials from goods containing silk, Richardson recommends treatment of the sample with a cold 2 per cent. solution of caustic potash; this not only removes any gum, but also decomposes any Prussian blue that may be present (as a bottom under the black dye), so that the iron may be more easily removed by subsequent treatment with a 1 per cent. solution of hydrochloric acid. Metallic mordants, however, are difficult to remove in this manner, and at best they dissolve only imperfectly; it is best to calculate their amounts from the quantity of ash left after the ignition of the sample.

Oily matter (and also certain dyes) may be best removed by boiling successively with methylated spirits and ether. By evaporation of the solution so obtained the amount of oil and fat may be directly determined.

Höhnel recommends the use of a semi-saturated solution of chromic acid (see p. 217) for the quantitative separation of mixtures containing wool, cotton, flax, true silk, and tussah silk. On boiling such a mixture of fibres in this solution for one minute, the wool and true silk will be completely dissolved, leaving as a residue the cotton, flax, and tussah silk.

Other methods given by Höhnel for the quantitative analysis of fabrics containing mixtures of the fibres mentioned above are as follows:

(a) Any true silk is first removed by boiling for half a minute in concentrated hydrochloric acid; tussah silk is next removed by a longer boiling in the acid (three minutes); the residue, con-

sisting of wool and vegetable fibres, is further separated in the usual manner by boiling in caustic potash solution.

(b) The fabric is first boiled in caustic potash solution, which dissolves the wool and the true silk, and leaves as a residue (*A*) tussah silk and vegetable fibre. A second sample is boiled for three minutes with concentrated hydrochloric acid, which dissolves both varieties of silk and leaves as a residue (*B*) wool and vegetable fibre. Residue *A* is then boiled three minutes with concentrated hydrochloric acid, which dissolves the tussah silk and leaves the cotton as a final residue. By subtracting this amount from residue *B* the amount of wool is obtained.

(c) A sample of the fabric is boiled for one minute in a semi-saturated solution of chromic acid, which dissolves the true silk and the wool, leaving as a residue the tussah silk and vegetable fibre. From this residue the tussah silk is removed by boiling for three minutes in concentrated hydrochloric acid, leaving the vegetable fibre as a final residue. A second sample is boiled for three minutes in concentrated hydrochloric acid, which dissolves the silks and leaves the wool and vegetable fibre as a residue. From this the amount of wool can be obtained either by boiling in caustic potash solution, or by subtracting the cotton previously estimated. Finally, the amount of true silk may be found by subtracting the sum of the other constituents from the total in the original sample.

5. Analysis of Weighting in Silk Fabrics.—The practice of adding to the weight of silk in the dyeing and finishing operations has become so common that it is frequently desirable to ascertain in a sample of silk goods the amount of true fibre present and the amount and character of weighting. Black-dyed silk is especially liable to contain a very large amount of weighting materials; sometimes the degree of weighting may reach as high as 400 per cent., or even more. Colored silks are usually not weighted to such a great extent, but they will frequently be found to also contain considerable adulteration. Black-dyed silks are mostly loaded with Prussian blue and iron tannate, the latter being obtained by immersing the silk in a solution of pyrolignite or nitrate of iron, and subsequently in a solution of cutch or other

tannin. Colored silks are principally weighted with tin phosphate obtained by treating the material with solutions of tin perchloride and sodium phosphate. Sometimes light colored silks are also weighted with sugar, magnesium chloride, etc. Such materials are soluble in warm water, and hence their use is easily detected.

A convenient test which is frequently applicable to detect weighting is to ignite the silk fibre; if it is heavily weighted it will not inflame, but gradually smoulder away and leave a coherent ash retaining the original form of the fibre.

In general the substances which may be present as weighting materials are iron, as ferrocyanide or tannate; tin, as tannate, tungstate, phosphate, silicate, or hydroxide; chromium compounds; the sulphates or chlorides of sodium, magnesium, and barium; organic matters, such as sugar, glucose, gelatin, tannins, etc.

The following method for the qualitative analysis of weighting materials on silk has been recommended by Silbermann:* Substances that are easily soluble, such as sugar, glucose, glycerin, magnesium salts, etc., are estimated directly by boiling the silk with water, and testing the extract with Fehling's solution, etc.† From 2 to 3 grams of the silk are ignited and the ash is tested for tin (which may be present in the fibre as basic chloride

* *Chem. Zeit.*, XVIII. 744.

† Fehling's reagent is an alkaline solution of copper sulphate containing potassium tartrate. It is prepared in the following manner: 34.639 grams of pure crystallized copper sulphate are dissolved in about 250 c.c. of water; 173 grams of Rochelle salt (sodium potassium tartrate) are dissolved in the same quantity of water; 60 grams of caustic soda are similarly dissolved. The three solutions are then mixed, and the mixture diluted to 1000 c.c. with water. The reagent is employed as follows: 10 c.c. of the solution are diluted with 40 c.c. of water and brought to a boil; there is then added a portion of the solution to be tested for sugar (or glucose) which has previously been boiled with a small quantity of dilute hydrochloric acid. If sugar is present, the Fehling's solution will be decolorized and a bright red precipitate of cuprous oxide will be thrown down. This test may be made quantitative by using a known quantity of sugar solution, filtering off the cuprous oxide, igniting, and finally weighing as copper oxide (CuO). In order to determine the amount of sugar (or glucose) corresponding to this latter, reference should be made to tables constructed by Allihn showing the proper equivalents of sugar and glucose for the amounts of copper oxide determined.

and stannic acid), chromium, iron, etc.* Fatty matters, wax, and paraffin are detected by extraction with ether or benzene.† The silk is soaked in warm dilute hydrochloric acid (1:2); if the fibre is almost decolorized by this treatment, only a slight yellow tint remaining, whilst the solution assumes a deep brown-

* These metals may be tested for in the ash in the following manner: Moisten with a few drops of nitric acid and re-ignite in order to be certain that all carbon is removed. Treat the residue with eight to ten drops of strong sulphuric acid, and gently heat until fumes are evolved; allow to cool and boil with water; dilute to about 100 c.c. with water, and then pass hydrogen sulphide gas through the liquid; filter, and examine the solution and precipitate as follows: The aqueous solution may contain zinc or iron; add a few drops of bromin-water to remove excess of hydrogen sulphide, and to oxidize any iron present to the ferric condition; boil, then add ammonia in slight excess; boil again, and filter; if there is a precipitate, it may contain iron; if so, it should be brown in color; dissolve in a little hydrochloric acid and add a few drops of a solution of potassium ferrocyanide; a blue color will confirm the presence of iron. The filtrate, which may contain zinc, should be heated to the boil, and a few drops of potassium ferrocyanide solution added; a white precipitate will indicate zinc. The original precipitate produced by the treatment with hydrogen sulphide is next examined. This may contain lead, tin, or copper; it is fused for ten minutes in a porcelain crucible with 2 grams of a mixture of potash and soda ash together with 1 gram of sulphur. On cooling, the mass is boiled with water and filtered. The residue may contain lead and copper; it is boiled with strong hydrochloric acid, and a few drops of bromin-water are added for the purpose of completely oxidizing any copper sulphide present; filter if necessary, and add to the filtrate an excess of ammonia, when a blue color will indicate presence of copper. Acidulate the liquid with acetic acid and divide into two portions: to the first add a few drops of a solution of potassium bichromate; a yellow precipitate will confirm the presence of lead; to the other add a few drops of a solution of potassium ferrocyanide, when a brown precipitate or coloration will indicate presence of copper. The filtrate from the residue after the above fusion is acidulated with acetic acid, when a yellow precipitate of stannic sulphide will indicate the presence of tin. The latter test may be confirmed by dissolving the precipitate of stannic sulphide in hydrochloric acid and bromin-water. The filtered solution is then boiled with small pieces of metallic iron to reduce the tin; the liquid is diluted and filtered and a drop of mercuric chloride solution is added, when a white or gray turbidity will be produced if tin is present.

† Japan tram silk is frequently weighted with fatty substances. The normal amount of fat in raw silk never exceeds 0.06 per cent. A direct determination of the fatty matters may be made by treating 5 grams of the silk sample in a stoppered flask with pure benzene three or four times successively, using about 60 c.c. of the solvent each time and allowing it to act from two to four hours with frequent shaking. The several portions of benzene are brought together and evaporated to dryness in a tared dish and the fatty residue is weighed. Another method is to extract with ether in a Soxhlet apparatus.

ish color not changed to violet by addition of lime-water, it is safe to conclude that the silk has been weighted by alternate passages through baths of iron salts and tannin. The yellow color of the fibre is due to a residuum of tannin, and the precise shade (from greenish to brownish yellow) enables some idea to be formed as to the nature of the tanning material used (sumac, divi-divi, cutch, etc.). Decolorization of the fibre, the acid extract being pink, and changing to violet by lime-water, indicates a logwood black. If the fibre retain a deep greenish tint and the solution be yellow and unaffected by lime-water, the black is dyed on a bottom of Prussian blue. If the latter has been produced during the final stage of dyeing, this will be shown by its solubility in the acid. A green fibre and pink solution, changing to violet on addition of lime-water, indicate a logwood black dyed on a bottom of Berlin blue. In the hydrochloric acid solution, such metals as lead, tin, iron, chromium, and aluminium may be determined. Blacks produced by artificial dyes on a bottom of iron-tannin or iron-blue-tannin may be recognized by the coloration imparted to acid and caustic soda solutions. With blacks produced solely with coal-tar dyes, treatment with a hydrochloric acid solution of stannous chloride does not affect anilin and alizarin blacks; naphthol black is changed to reddish brown, and wool black becomes yellowish brown. Tannin materials in general may be extracted by alkalies, and subsequently precipitated and distinguished by ferric acetate. To remove the whole of the weighting material and the dye, the silk should be boiled with acid potassium oxalate, washed with dilute hydrochloric acid, and finally treated with soda solution. When iron and tin are both present in the fibre, it is best to first extract the tin by treatment with a solution of sodium sulphide.*

Vignon has proposed using the specific gravity of the silk sample as a means of determining the proportion of weighting materials present; but this method cannot be recommended as

* Persoz recommends in testing for tin weighting on dark colored and black silks to boil the sample for a few minutes in concentrated hydrochloric acid. Then dilute and filter the acid, and pass hydrogen sulphide into it, when a yellow precipitate (SnS) would indicate the presence of tin.

being at all practical, as the specific gravity of the weighting materials themselves would have to be known. The specific gravity of the silk may readily be determined as follows: A small sample is weighed as usual in the air; it is then suspended in benzene and the weight again taken. The difference between the two weighings will give the loss of weight in benzene; this loss divided into the original weight in air and multiplied by the density of the benzene will give the specific gravity of the silk. The specific gravity of silk and of other fibres determined in this way is given as follows:

Silk, raw.....	1.30 to 1.37
Silk, boiled-off.....	1.25
Wool.....	1.28 to 1.33
Cotton.....	1.50 to 1.55
Mohair.....	1.30
Hemp.....	1.48
Ramie.....	1.51 to 1.52
Linen.....	1.50
Jute.....	1.48

For the examination of white silk Allen recommends the following:* (1) The total *soluble weighting materials* are determined by treating a known weight of the sample four to five times with hot water, redrying, and weighing. As the hygroscopic character of silk is very variable, it is best to employ a blank sample of a standard silk, and after redrying until the blank sample has regained its normal weight the test sample is weighed, and the loss represents the matters soluble in water. In the solution, after suitable evaporation, *glucose* may be determined directly by means of Fehling's solution (see p. 259), and *cane-sugar* after inversion by boiling with dilute hydrochloric acid. *Sulphates* and *chlorides* and *magnesium*† may be detected and

* *Commer. Org. Anal.*, vol. IV. 527.

† Sulphates are detected by taking a small portion of the solution in a test-tube, adding a few drops of dilute hydrochloric acid and then a few drops of a solution of barium chloride; the production of a white precipitate indicates the presence of sulphates. Chlorides are detected by adding a drop of nitric acid to a test portion of the solution, and then a few drops of a solution of silver nitrate; a white precipitate will indicate the presence of chlorides. Magnesium is detected by adding to the test portion of the solution a few drops of ammonia

determined as usual. *Stannic oxide* (if the silk has been weighted with tin compounds) will be left as a white residue on igniting a sample of the silk in a porcelain crucible. If much tin is present, the silk will burn with difficulty, and the ash will retain the shape of the original silk. The weight of the ash (assuming it to be wholly stannic oxide, SnO_2) may be calculated to the form in which the tin exists in the weighted silk (as metastannic acid, $\text{SnO}_2 \cdot \text{H}_2\text{O}$) by multiplying it by the factor 1.12.

Silbermann* recommends for the analysis of white silk the further procedure: A weighed portion of the silk is boiled with dilute hydrochloric acid to dissolve any tannin lakes of tin or other metals, and in the solution tannin is tested for by the addition of an excess of sodium acetate and ferric chloride. If tannin lakes are present, the determination of the weighting materials consists in: (1) precipitation of the tannin from the aqueous solution with gelatin; (2) estimation of the tannin in this precipitate, and of sugar, etc., in the filtrate; (3) successive treatment of the silk with dilute hydrochloric acid and sodium carbonate, and precipitation of tannin from both solutions by means of gelatin; (4) ignition of the silk and determination of metallic weighting. If the ash is not completely soluble in hot moderately concentrated hydrochloric acid, it may contain barium sulphate or silica. To calculate the percentage of weighting material, W , in the silk examined, Silbermann employs the following formula, in which a is the weight of the sample before treatment, b the weight after extraction with water, p the stannic oxide left on ignition, and d the loss in weight during the boiling of the fibre itself. This is taken at 20 to 25 for boiled-off silk, 5 to 9 for souple silk, and 0 to 2 for écreu.

$$W = \frac{a(100 - d)}{b - 1.13p} - 100.$$

followed by a solution of sodium phosphate; the formation of a white precipitate indicates the presence of magnesium. These tests may be made quantitative by taking definite aliquot portions of the solution, collecting the precipitates produced, and after ignition in a porcelain crucible weighing as barium sulphate, BaSO_4 , silver chloride, AgCl , and magnesium pyrophosphate, $\text{Mg}_2\text{P}_2\text{O}_7$, respectively.

* *Chem. Zeit.*, xx. 472.

The detection of tin or aluminium compounds in the weighting of white silk may be carried out by dyeing a sample of the silk with alizarin in the presence of chalk, then rinsing and soaping. Unweighted silk will retain only a pink color; if weighted with tin, the color will be orange, and if weighted with aluminium, the color will be red.

Dark colored and black silk may contain hydroxides of tin, iron, and chromium, fatty matters, tannin, Prussian blue, and various coloring-matters. Treatment of logwood-dyed silk with hydrochloric acid (1.07 sp. gr.) at 50° to 60° C. will give a red color in the absence of Prussian blue, or leave a blue-black color if it is present. If Prussian blue is suspected, the silk should be treated with dilute caustic soda, the solution then acidulated with hydrochloric acid, and a few drops of a solution of ferric chloride then added; a blue precipitate will be produced if Prussian blue was originally present. The metallic oxides in the residue left on igniting a sample of the silk are best examined by fusing the ash with a mixture of nitre and sodium carbonate in a platinum or silver crucible. The fusion is treated with water, when the tin and chromium will go into solution as sodium stannate and chromate respectively, and the iron will remain insoluble as ferric oxide. After filtering and acidulating the filtrate with hydrochloric acid, the tin may be thrown down as sulphide by treatment with hydrogen sulphide, and after filtering off the latter the chromium is precipitated by addition of ammonia. For the detection of tannin a sample of the silk should be boiled in water, and a few drops of a solution of ferric acetate added, when a blue-black color is produced in the presence of tannin. The amount of tannin may be determined by dissolving it from the silk by means of an alkaline soap-bath, and finding the loss of weight on redrying. To determine the total proportion of weighting materials, a definite quantity of the silk dried at 110° C. should be boiled for an hour in a 2 per cent. solution of caustic soda, and then in dilute hydrochloric acid (250 c.c. of commercial acid per litre). This treatment is repeated four times, washing the sample between each bath. The silk must be carefully handled, as it becomes quite brittle; after drying at 110° C. it

is weighed; the loss in weight represents the total weighting materials. As a certain loss of silk occurs in this treatment, the amount of weighting material found is generally somewhat in excess of the truth. The chief source of error, however, is in the uncertainty of the allowance to be made for loss in the weight of the silk by boiling off. For boiled-off silk this figure (d) is taken at 25 per cent.; for souple silk at 8 per cent.; for écreu at 0 per cent.; and for fancy silks at 10 per cent. Calling p the original weight of the sample, and D the weight after treatment, the percentage of weighting, W , may be calculated from the following formula:

$$W = \frac{(100-d) \times (p-D)}{D}.$$

In cases where the treated silk leaves a sensible amount (A) of ash on ignition, the following formula must be used:

$$W = \frac{(p-D+1.25A) \times (100-d)}{D-1.25A},$$

as the weight of the ash, if multiplied by the factor 1.25, will give approximately the amount of metallic hydroxides retained by the treated silk.

The foregoing method of Silbermann is not sufficiently accurate for such a long and tedious process.

The method of analyzing weighted silk recommended by Königs of the silk-conditioning establishment at Crefeld is as follows: (1) Determine *moisture* by drying at 110° C. (2) *Fatty matters* by extraction with ether. (3) Boil out the *silk-glue* with water. (4) Dissolve out Prussian blue with dilute caustic soda; reprecipitate by acidifying and adding ferric chloride, ignite precipitate with nitric acid, and weigh as ferric oxide; 1 part of Fe_2O_3 = 1.5 parts of Prussian blue. (5) Estimate stannic oxide in ash of silk and calculate as catechu-tannate of tin; 1 part of SnO_2 = 3.33 parts of catechu-tannate. (6) Estimate total ferric oxide in ash, subtract that existing as Prussian blue, and the amount naturally present in dyed silk (0.4 to 0.7 per cent.), and calculate the remainder to tannate of iron; 1 part of Fe_2O_3 = 7.2 parts of ferric tannate.

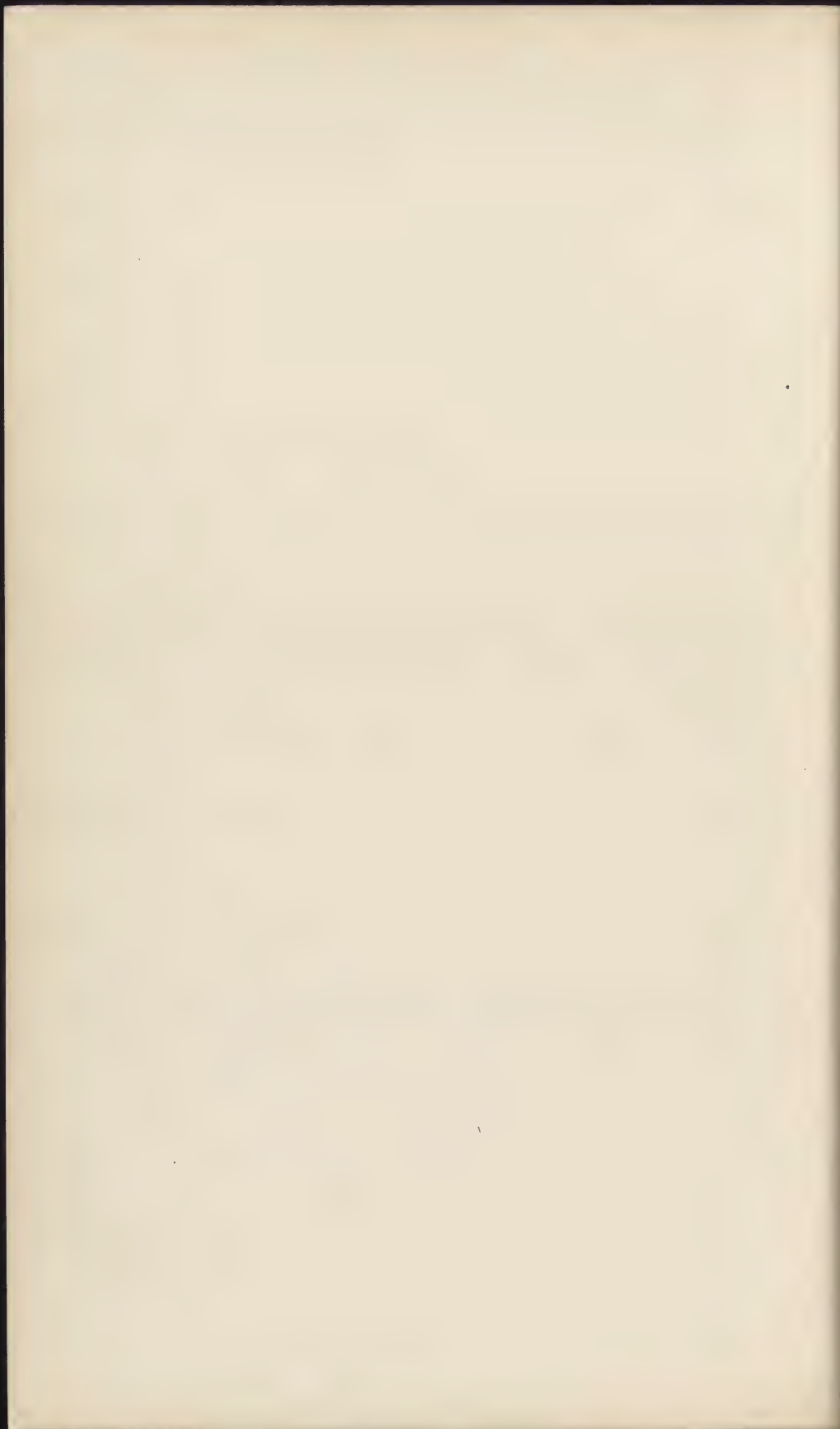
Perhaps the most accurate method of analyzing silk for total amount of weighting is to determine the amount of nitrogen present as silk by Kjeldahl's process.* To do this it is first necessary to remove all gelatin, Prussian blue, or other nitrogenous matters. This is effected by boiling a weighed quantity of the silk (about 2 grams) with a 2 per cent. solution of sodium carbonate for thirty minutes. The silk is then washed, and heated to 60° C. for thirty minutes in water containing 1 per cent. of hydrochloric acid, and afterwards well washed in hot water. This treatment with alkali and acid should be repeated until the sample no longer has a blue color. With *souple* or *écru* silks, ammonia or ammonium carbonate should be used instead of sodium carbonate, and the silk should be finally boiled for an hour and a half in a solution containing 25 grams of soap per litre. After this preparation the nitrogen determination is conducted as follows: The sample is placed in a round-bottomed flask of hard glass, and treated with about 20 c.c. of strong sulphuric acid, with the addition of a single drop of mercury. The flask is then heated, gently at first, and then to a vigorous boil; then 10 grams of potassium sulphate are added and the boiling continued until the contents of the flask are clear and colorless. The contents are then washed into a distilling-flask and connected with a suitable condenser. By means of a tap-funnel an excess of caustic soda solution is gradually added, together with a little sodium sulphide to decompose any nitrogen compounds of mercury that may have been formed. Some granulated zinc is placed in the flask to prevent bumping, and the distillate is collected in a measured quantity of standard acid, which takes up the ammonia that distils over. Excess of acid is determined by titration with standard alkali, using methyl orange as an indicator of neutrality. The above method is based on the fact that when silk (in common with the great majority of other nitrogenous organic substances) is heated with concentrated sulphuric acid, the whole of the nitrogen present is eventually converted into ammonia. Air-dried silk with 11 per cent. of hygroscopic moisture contains

* Gnehm and Blenner, *Rev. Gen. Mat. Col.*, April, 1898.

17.6 per cent. of nitrogen, consequently the amount of true silk in a sample may be obtained by multiplying the percentage of nitrogen found by the factor 5.68. This method yields very accurate results if the determination of the nitrogen is carefully conducted.

A method for the determination of the weighting on silk which appears to be capable of yielding very good results is that suggested by Gnehm.* It depends on the fact that the silk fibre does not appear to be injured by treatment with either hydrofluosilicic acid or hydrofluoric acid. The method is carried out as follows: About 2 grams of the silk to be tested are immersed, with frequent stirring, for one hour at the ordinary temperature in 100 c.c. of a 5 per cent. solution of hydrofluosilicic acid. The treatment is then repeated with 100 c.c. of fresh acid of the same strength. The silk is then washed several times with distilled water and dried. The loss in weight corresponds to the amount of inorganic weighting materials present. This method serves very well with silk weighted with stannic phosphate and silicate, but does not appear to be suitable for the estimation of weighting on black-dyed silks containing iron salts. It is said that oxalic acid may also be used (Müller, *Zeits. Farben-u. Text. Chem.*, 1903, 160) for the purpose of removing the inorganic weighting materials from silk, without injury to the silk fibre itself.

* *Zeits. Farben-u. Text. Chem.*, 1903, 209.



APPENDIX I.

MICROSCOPIC ANALYSIS OF FABRICS.

HÖHNEL describes the following method employed for a microscopic examination of textile fabrics, where the object is to determine not only qualitatively the character of fibres composing them, but also their quantitative amounts. With regard to the preliminary qualitative examination, there are generally only a few fibres to be taken into consideration, as there seldom occur in the same fabric more than one to four different kinds of fibres. As a rule, the only fibres which will be found are cotton, linen, hemp, jute, ramie, sheep's wool, goat-hair, cow-hair, angora, alpaca, cashmere, llama, silk, and tussah silk. In woolen material there are also cosmos and shoddy to be considered.

To undertake the examination, cut off a sample of the material 2 to 3 sq. cm. in size, and separate this into its warp- and filling-threads. The sample must be of sufficient size to include all of the different kinds of yarns employed in the weave. Consequently in the case of large patterns it has to be rather large. The warp- and filling-threads are laid next to each other, and one of each kind is selected to serve for further examination. In the simplest case there is only one kind of warp-thread and one kind of filling present, which necessitates, therefore, the examination of only two different yarns. In complicated cases there may be as many as ten, or even more, different yarns to analyze. In woolen fabrics there will frequently be found yarns which are composed of two or three different threads twisted together; these must be untwisted and each separate yarn examined by itself. In order to attain satisfactory results, the operator must be sufficiently skilled in the microscopy of the fibres to be able to recognize with certainty, under a low magnification, the different

fibres liable to be found. By a low magnification is meant one of fifty to sixty times. A much higher power cannot be used in the examination of fabrics, for hundreds or even thousands of fibres have to be taken into consideration. From ten to twenty fibres, or perhaps more, should be obtained in the field at the same time, and it is necessary to be able to promptly recognize the different ones. With a higher magnification, it is true, the single fibres can be better recognized, but the general view is then lost, and there is danger in overlooking whole bundles of fibres. If the observer finds a fibre which cannot be recognized with sufficient accuracy by means of the low power, it is a simple matter to so change the objective as to increase the magnification to allow of the necessary observations to be made, and then to proceed again with the examination under the lower power.

Dark colored material often consists for the most part of threads which, on microscopic examination, appear quite opaque, hence dark and structureless. Therefore it will frequently be necessary to remove the dyestuff, at least in part, which is usually done by boiling in acetic acid, hydrochloric acid, dilute caustic alkali, potassium carbonate, etc., until sufficiently light in appearance.

In the case of very accurate examinations, each different kind of thread must be examined separately, and the number of fibres composing it, together with their kind and color, must be noted. In order to show the detail and scope of such an examination, the following example is given: On unravelling a sample four different warp-threads and one filling-thread were obtained. One of the warp-threads was composed of two yarns twisted together, one of which was black (K_1a) and the other white (K_1b). Two warp-threads were dark blue (K_2 and K_3) and the fourth was a gray mix (K_4); the filling-thread (E) was blue. On examination the following results were obtained:

K_1a showed 85 shoddy fibres (mostly black, some yellow and red, and even isolated green fibres of wool, and 13 cotton fibres).

K_1b showed 31 pure white wool fibres.

K_2 and K_3 , respectively, showed 46 and 53 pure blue wool fibres.

K_4 showed 60 shoddy fibres, of which 32 were mostly gray or black wool fibres, and 28 were gray cotton fibres.

E showed 60 blue wool fibres.

Therefore in this sample, including 4 warp- and 4 filling-threads, there would be $85 + 31 + 46 + 53 + 60 = 275$ single warp fibres; and $60 \times 4 = 240$ filling fibres; or 515 single fibres altogether. Of these 41 were cotton, which were found in the shoddy, the latter comprising 145 fibres in all. Hence in a sample of this piece of goods containing equal lengths of warp and weft, there are 41 cotton fibres, 104 shoddy-wool fibres, and 370 pure-wool fibres, from which the respective percentages would be:

	Per Cent.
Cotton.....	8.0
Shoddy-wool.....	20.2
Pure-wool.....	71.8
	<hr/>
	100.0

This, of course, only gives the relative percentages of the number of fibres; if it is desired to reach an approximate idea of the proportions by weight, then micrometric measurements must be made of the wool and cotton fibres occurring in the sample. In consideration of the fact that wool possesses about twice the cross-section of cotton, it becomes a rather easy matter to calculate the ratio between the two, by means of which the percentage by weight can be readily obtained, provided that the specific gravity of wool is taken to be about the same as that of cotton, which is approximately true.

APPENDIX II.

MACHINE FOR DETERMINING STRENGTH OF FIBRES.

THERE have been a number of machines devised for the purpose of determining the tensile strength and elasticity of fabrics and yarns, and a few instruments have also been adapted for the testing of single fibres. As the individual fibre, however, is a very slender and delicate object, especially in the case of certain vegetable fibres, the determination of its physical factors is an operation which requires a delicately adjusted apparatus. In machines which require the taking on or off of weights, the jar is usually sufficient to break the fibre before its true breaking strain is reached. The same criticism is also true for machines employing water as a weight. A machine devised for the use of the Philadelphia Textile School has proved very satisfactory for determining the tensile strength and elasticity of almost any fibre, from very fine and delicate filaments to coarse and strong hairs. A diagrammatic drawing of this machine is given in Fig. 69. The fibre to be tested is clamped between the jaws at (*J*), the pointer attached to the end of the beam above the upper jaw being brought to the zero-mark on the scale (*S*), while the lower jaw is raised or lowered in its stand until the desired distance between the jaws is obtained. To obtain comparable results this distance should always be the same; and 10 cm., in the case of long fibres, or 2 cm. for short fibres, have proved to be good lengths of fibre to test. The sliding-bar (*R*) is moved forward by turning the rod (*T*), which moves the rack and pinion at (*P*), until the graduation on the wheel (*G*) is at zero to the indicator. Under these conditions there is no strain on the fibre. A stretch-

ing-force is then placed on the fibre by moving the bar (*R*) backward by turning the rod (*T*); the motion of this bar is made uniform and gradual until the fibre finally breaks under the strain thus placed upon it. The graduation on the wheel (*G*) will then indicate in decigrams the breaking strain of the fibre being tested. The elasticity is obtained by watching carefully the pointer moving up the scale of millimeters at (*S*) until the rupture

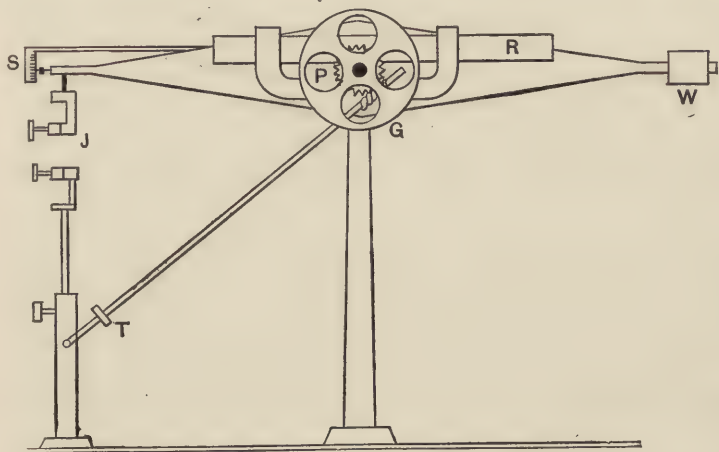


FIG. 69.—Fibre-testing Machine of Reeser & Mackenzie.

J, jaws with screw-clamps for holding the fibre; the lower jaw may be raised or lowered; *R*, sliding-rod working on a rack and pinion; this takes the place of weights; *G*, wheel graduated on its face in decigrams, moving on the same axis as the pinion for sliding the weight; *T*, thumb-screw for turning the small shaft working the pinion at *P*; *W*, counterbalancing weight for regulating the zero-point of the machine; *S*, scale for reading the stretch of the fibre.

of the fibre takes place; the distance this pointer moves represents the actual stretch of the fibre; and if the length of fibre taken between the jaws is 10 cm., this figure will represent directly the percentage of elasticity. If the length of fibre taken is only 2 cm., to obtain the percentage of elasticity it is necessary to multiply the amount of stretch in millimeters by five; and for other lengths of fibre similar proportions will hold. The weight (*W*) at the rear end of the beam can be moved backward or forward, and is for the purpose of adjusting the balance so that there is no strain at (*J*) when the indicator on (*G*) marks zero. The wheel

(*G*) is graduated in decigrams, and this marks the sensibility of the machine; the total graduations on (*G*) running from zero to 400. When fibres are tested having a greater tensile strength than 400 decigrams a fixed additional weight of 10, 25, 50, etc., grams may be hung from (*W*), and this must be added to the reading on the wheel when the fibre breaks. If the elasticity of the fibre is so great as to carry the pointer beyond the limits of the scale at (*S*), a shorter length of fibre must be tested. A fair average of breaking strain and elasticity may be obtained for any quality of fibre by testing about 10 separate fibres and taking a mean of the total tests. If the quality of the fibres, however, in a sample does not run very uniform, it is best to increase the number of tests to 25 or even 50 in order that a satisfactory average may be obtained.

This machine is capable of being used with all classes of fibres, and its results are very satisfactory, as has been proved by several years' use at the Philadelphia Textile School.*

* This machine is made by Reeser & Mackenzie of Philadelphia.

APPENDIX III.

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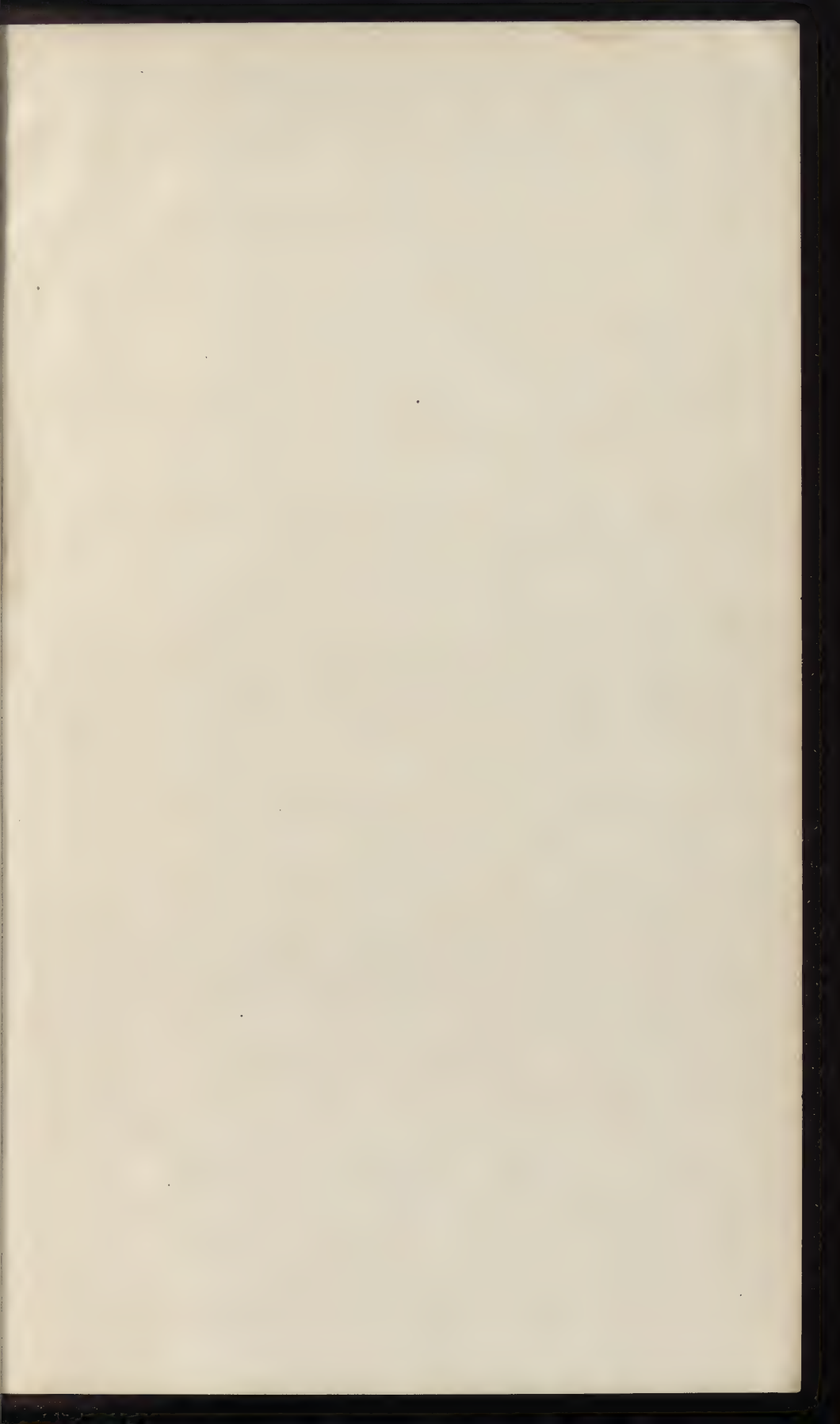
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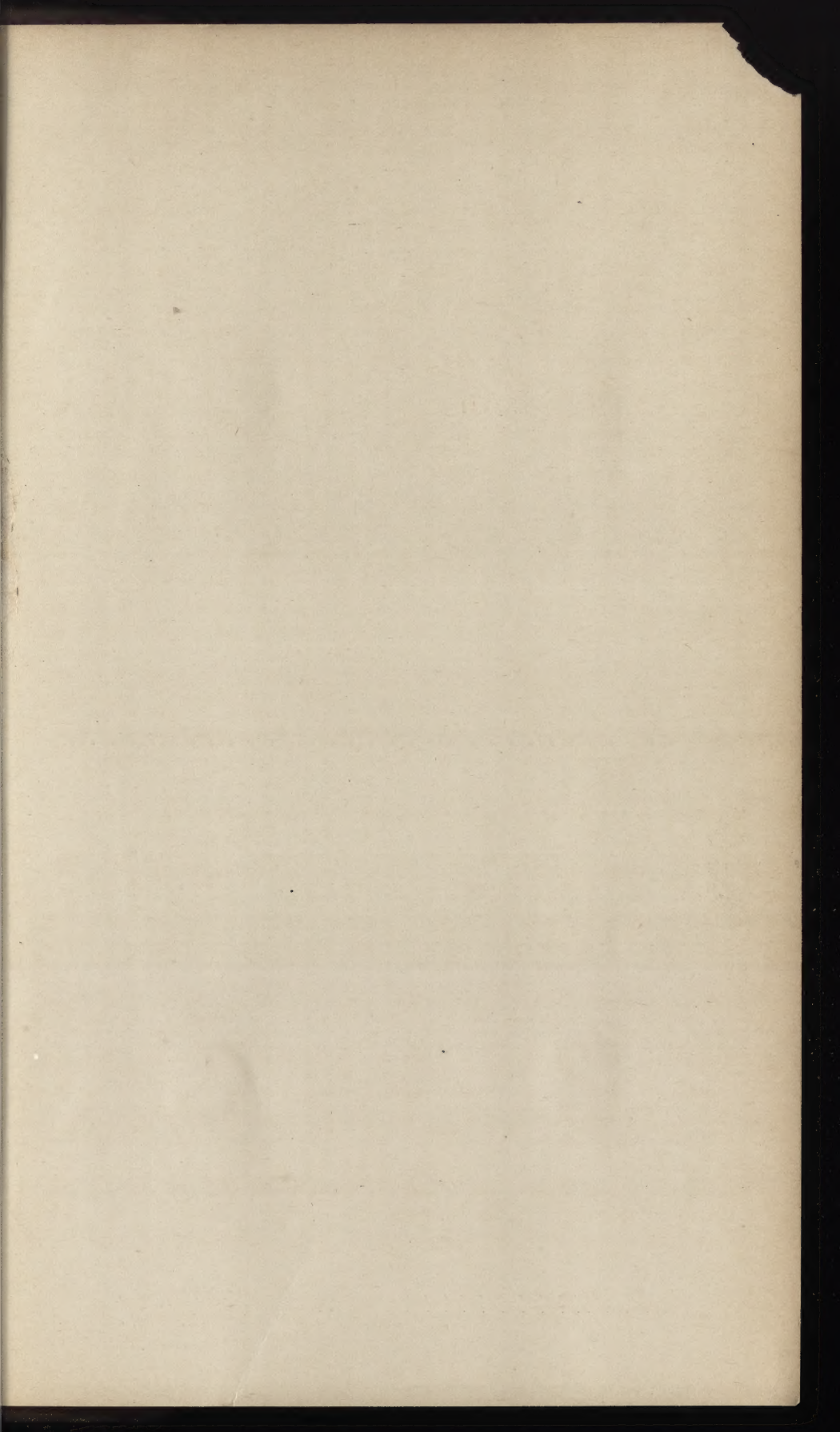
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